SEWERAGE AND SEWAGE DISPOSAL

HENRY ROBINSON, C.E.

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PREFACE.

HAVING had occasion in my own practice to investigate the information which of recent years has become available to engineers, through the researches of chemists and biologists, in relation to Water Supply, Sewerage and Sewage Disposal, I have thought that a concise summary of the most important data would be useful. I have confined this book as far as possible within the limits of data in connection with works of Sewerage and Sewage Disposal, although in dealing with River Pollution and Filtration of Impure Water, the allied subjects of Water Pollution and Sewage Purification necessarily overlap. In fact, the functions of micro-organisms, which affect the consideration of both, must be well understood by engineers who have to advise in regard to them.

I have also summarised the chief conditions

requiring to be complied with in the drainage of houses and in the sewering of towns. The calculations of flow in sewers are also dealt with, and the diagram, at the end of the book, of discharges and velocities in oval and circular sewers will enable results to be rapidly scaled.

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SEWERAGE

AND

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CHAPTER I.

HOUSE DRAINAGE.

The most important points for practical guidance in reference to house drainage are as follows.

The subsoil of a building should be drained, if it is a damp one, and the drains (necessarily open-jointed ones) should not connect with a cesspool, or sewer, so as to bring foul gases under and around the house. A dry area should be made to prevent damp coming through walls into rooms below the ground level. If this cannot be done, a hollow wall will prevent damp passing through, as a damp course will prevent it passing up. A layer of concrete under the whole basement is desirable, to avoid the possibility of subsoil moisture and foul gases passing into the house.

House drains should be effectually trapped from the main sewer, and the trap should be placed as

far from the house as possible, with a fresh air inlet on the house side of the trap to ensure a current of air passing through the house drain up the soil pipe.

House drains should not be less than four inches in diameter. They should not be laid under buildings if possible. If they cannot be laid outside, then at least six inches of concrete should be placed round them. Even when they are outside it is best to lay them on a bed of concrete.

When house drains are laid under buildings provision should be made for ventilation at both ends; that is, there should be a current of air through the drain. When the house drain has too flat a gradient a Field's automatic flush tank should be placed at the head of it to prevent deposits forming.

The cistern for a water-closet should be distinct from that for supplying water for dietetic purposes. The flush should be three gallons, conveyed by a pipe not less than 1¼ inches internal diameter. The three gallons flush is greater than has hitherto been employed as a general rule, but it is considered desirable to adopt this to ensure the complete cleansing of the closet and soil pipe, as well as to ensure the removal of the filth from the house drain to the sewer. The greater flush is objected to by those who aim at minimising the consumption of water, but the avoidance of the unhealthy condition inseparable from too small a flush, should prevail over economy in water consumption. The trap of

a closet ought to be ventilated to the open air to prevent the water seal being syphoned out.

Rain-water pipes should be cut off from direct communication with the drain, and should discharge on to a trapped gully. Waste pipes from baths, sinks, lavatories, &c., should be taken through the external wall and discharged into a channel leading to a trapped gully. Only excremental filth from closets or stool sinks should discharge into the soil pipe.

The soil pipe should be at least $3\frac{1}{2}$ inches in diameter, and should be outside, and not inside the house. It should be continued full bore, without bends, above the roof, and away from windows or chimneys, to prevent foul gases passing into the house.

Water-closets should be placed so as to have one side next an external wall, with a window opening to the outer air, and with provision for ventilating the closet, which should not be approached directly from any room used for human habitation.

The connection between soil pipes and drains should be by an oblique junction in the direction of the flow. An inlet for fresh air should be provided between the soil pipe and the disconnecting trap to the main sewer.

House drains should be tested to ensure their being watertight. The sewer end should be closed

temporarily, and the drain filled with water standing (by a temporary vertical pipe) a few feet above the level of the house end. When the soundness of the work has been ascertained by the water level not falling, the drain can be covered up. The connection between a house and the sewer should be inspected and certified by a competent person before the ground is closed.

The construction of house drains is dealt with hereafter when considering the construction of stoneware sewers.

A certificate from the local sanitary authority should be required before a house is deemed fit for human habitation. It should be held as important for a house to be wholesome before it is let or sold, as for food to be wholesome, and inasmuch as there exist statutory powers under which food that is unfit for consumption is condemned and destroyed, why should there not be similar legislation to meet the case of house property that is unfit for habitation?

In the United States, legislation has made it a penal offence for bad plumbing to be done in a house. Considering the injury to health which results from the work of the plumber being executed negligently, some such legislation would be useful in this country. The granting of certificates to plumbers is a step in the right direction.

CHAPTER II.

MEMORANDA.

A GALLON of water weighs 10 lbs.

1 cubic foot of water weighs 62·4 lbs. and = 6·23 gallons.

1 cubic inch weighs ·036 lbs. and = ·0036 gallons.

1 cwt. = 1·8 cubic feet = 11·2 gallons.

1 ton = 35·9 cubic feet = 224 gallons.

One inch in depth of sewage over an acre of land is equivalent to—

101 tons,
or 22,620 gallons,
or 3630 cubic feet.

The average total dry matter in sewage varies in different countries. In Messrs. Rafter and Baker's work on American Sewerage they give the following table :—

CONSTITUENTS OF SEWAGE.

	Dissolved Matter.	Suspended Matter.	Total dry Matter.
2000 lbs. Boston sewage ..	1·179	0·747	1·926
2000 lbs. Worcester sewage ..	0·507	0·423	0·930
2000 lbs. Berlin sewage	1·578	0·102	1·680
2000 lbs. sewage, average of 50 English towns	1·444	0·894	2·338
Organic	0·276	0·603	0·879
Inorganic	1·146	0·778	1·924
	1·422	1·381	2·803

From the researches of Wolff and Lehman the following data are tabulated :—

WEIGHT IN POUNDS OF THE SOLID AND LIQUID EXCREMENTS OF A MIXED POPULATION OF 100,000 PERSONS FOR A YEAR.

Population, by Sex and Age.	Fæces.			Urine.		
	Total.	Organic Nitrogen.	Phosphates.	Total.	Organic Nitrogen.	Phosphates.
37,610 men ..	4,521,664	52,416	98,672	45,217,782	452,144	183,456
34,630 women..	1,237,040	28,000	30,038	37,458,512	297,136	151,648
14,060 boys ..	1,239,504	20,496	18,122	6,423,670	53,872	24,304
13,700 girls ..	274,736	6,270	4,032	5,041,344	40,320	19,152
Totals ..	7,272,944	107,182	150,864	94,141,308	843,472	378,560

WEIGHT IN GRAINS OF THE SOLID AND LIQUID EXCREMENTS PER PERSON PER DAY, AND THE ORGANIC NITROGEN AND PHOSPHATES CONTAINED THEREIN.

Sex and Age.	Fæces.			Urine.		
	Total.	Organic Nitrogen.	Phosphates.	Total.	Organic Nitrogen.	Phosphates.
Men	2,315	27	50	23,148	231	94
Women ..	694	16	17	20,833	166	85
Boys .. .	1,698	29	25	8,796	73	33
Girls	386	9	6	6,944	57	27
Means ..	1,273	20	25	14,930	132	60

WEIGHT IN POUNDS OF THE SOLID AND LIQUID EXCREMENTS PER PERSON PER YEAR.

Sex and Age.	Fæces.			Urine.		
	Total.	Organic Nitrogen.	Phosphates.	Total.	Organic Nitrogen.	Phosphates.
Men	120·45	1·39	2·62	1,204·5	12·04	5·28
Women ..	36·08	0·80	0·86	1,083·9	8·61	4·38
Boys	88·33	1·51	1·29	457·7	3·79	1·73
Girls	20·07	0·46	0·29	361·3	2·95	1·40
Means ..	66·23	1·04	1·26	777·68	6·85	3·20

AVERAGE COMPOSITION OF HUMAN EXCREMENTS.

(*Per cent.*)

Kind.	Water.	Organic Matter.	Nitrogen.	Phosphoric Acid.	Potash.	Lime.	Magnesia.
Fresh human fæces	77·2	19·8	1·00	1·10	0·25	0·62	0·36
Fresh human urine	96·3	2·4	0·6	0·17	0·20	0·02	0·02
Mixture of the two	93·5	5·1	0·7	0·26	0·21	0·09	0·06

Messrs. Lawes and Gilbert give the following as the amounts of different substances in the solid and liquid excrements of an adult male in a year :—

DRY SUBSTANCE: fæces, 23·75 lbs.; urine, 34·5 lbs.; total, 58·5 lbs.

MINERAL MATTERS: fæces, 2·5 lbs.; urine, 12 lbs.; total, 14·5 lbs.

CARBON: fæces, 10·0 lbs.; urine, 12 lbs.; total, 22 lbs.

NITROGEN: fæces, 1·2 lbs.; urine, 10·8 lbs.; total, 12 lbs.

PHOSPHORIC ACID: fæces, 0·7 lbs.; urine, 1·93 lbs.; total, 2·63 lbs.

According to Wolff, the amount of potash from the excrements of an adult male per year is—

Fæces, 0·24 lbs.; urine, 2·01 lbs.; total, 2·25 lbs.

MEAN OF ANALYSES OF LONDON SEWAGE MADE BY MR. W. J. DIBDIN IN 1883. (*Parts per* 100,000.)

	Number of Samples in series.	Dissolved Solids.			Ammonia.		Chlorine.	Suspended Matter.		
		Total.	Mineral.	Organic.	Free.	Albuminoid.		Total.	Mineral.	Organic.
Samples from southern outfall.	109	88·3	60·9	27·4	4·16	·523	18·0	37·5	16·7	20·7
Samples from northern outfall.	72	79·4	51·6	27·9	5·05	·584	12·4	41·6	19·5	22·0
Average from both outfalls.	181	83·9	56·2	27·7	4·60	·553	15·2	39·6	18·1	21·4
Percentage composition	..	100·0	67·0	33·0	..	..	..	100·0	46·0	54·0

AVERAGE COMPOSITION OF THE SEWAGE EXPERIMENTED UPON AT LAWRENCE, MASSACHUSETTS, FOR FOUR YEARS. (*Parts per* 100,000.)

Year.	Free Ammonia.	Albuminoid Ammonia.			Chlorine.	Oxygen consumed.	Bacteria per Cubic Centimeter.
		Total.	Soluble.	Insoluble.			
1888	1·5528	·6878	·1611	·5267	5·19	..	1,000,000
1889	1·8439	·5540	·2909	·2631	4·92	..	708,000
1890	1·8200	·6862	·3805	·3057	5·45	3·25	1,085,000
1891	2·2196	·7295	·3446	·3849	7·37	3·64	693,000
Average 4 years	1·8591	·6644	·2943	·3701	5·73	3·44	871,000

Experiments with sewage have been carried on at the Lawrence station of the Massachusetts State Board of Health, and are referred to hereafter. The table on page 9 gives the composition of the sewage experimented with.

The first report of the Rivers Pollution Commissioners contains the following table :—

AVERAGE COMPOSITION OF SEWAGE OF ENGLISH TOWNS.

(*Parts per* 100,000.)

Classes of Towns.	Total Solids in Solution.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Total combined Nitrogen.	Chlorine.	Suspended Matter.		
							Mineral.	Organic.	Total.
Midden towns ..	82·4	4·181	1·975	5·435	6·451	11·54	17·81	21·30	39·11
Water-closet towns	72·2	4·696	2·205	6·703	7·728	10·66	24·18	20·51	44·69

CHAPTER III.

SEWERAGE.

In calculating the volume which the sewers in a town have to carry off it is important at the outset to decide whether the large bulk of the rainfall can be excluded from the sewers.

Much of the difficulty which attends sewage disposal arises when the outfall sewer is made to convey also the whole of the rainfall. This ought not to be the case where avoidable, as the separation of the rainfall—or at all events of a considerable part of it—enables the sewers to be designed so as to be self-cleansing, and the sewage which is removed by them is brought to the point of discharge in a fresher state than is possible where the sewers are calculated to convey the larger volume, as they become sewers of deposit in dry weather. In wet weather the decomposing sewage is flushed away to the outfall in a state which is unsuitable for utilisation on land, or for treatment with chemicals. The exclusion of the bulk of the rainfall is of great importance where the sewage has to be pumped.

If separate clean water sewers can be provided

to carry off the bulk of the rainfall to the natural watercourses, the volume of sewage passing into the sewers will not be subject to the wide fluctuations that are unavoidable when all the rainfall enters. That which is admitted should be limited, if possible, to the rain falling on roofs, yards, courts, back areas, paved surfaces, &c., which become highly polluted in large towns. The separate system is not applicable everywhere, and much consideration requires to be given to the circumstances of each case.

Sewage, including rainfall from roofs, yards, &c., may be taken at about six cubic feet per head per day, of which one-half would be discharged in six hours. That which flows off beyond this amount (which will be a variable quantity) should be carried off by separate sewers, or by storm overflows. A rainfall at the rate of 12 inches in an hour was gauged in 1878 by Mr. Symons at Camden Town, but it lasted only thirty seconds. In September 1895, he gauged ·54 of an inch in five minutes, and 1 inch in ten minutes. Much, however, would be either absorbed or evaporated, or would not reach the sewer at the same time.

The first flow off town roads with much horse traffic (however good the scavenging may be), is very foul, and should be carried to the outfall. After this has passed away the subsequent volume is comparatively clean water, and may be discharged by storm overflows, which act either by relieving the

sewer when the level of the sewage reaches a certain height, or when the sewage shoots over a weir after a certain velocity has been attained. These prevent the sewer from getting under pressure, when the house drains become gorged. In calculating the size of a sewer the volume that has to be dealt with in a limited time governs the whole matter. One inch of rainfall an hour would represent 3630 cubic feet per acre of surface per hour. This quantity, however, flows off the whole area at different rates according to the condition of the surfaces, and the possibility of a sewer having to receive the maximum rainfall, is confined to small areas, the calculations for which would apply to tributary sewers and not to outfalls.

The Royal Commission on Metropolitan Sewage Discharge reported in 1884 that 75,251 acres represented the area sewered, the population on which was 2,656,000, the number varying from 7·3 to 253 per acre, and the volume varying from 0·04 cubic feet per acre per minute to 0·83, the average maximum being ·14 cubic feet per acre per minute. It has been estimated that there are on an average 1800 people per mile of sewer in London. At Berlin, the population density varies from 220 to 25 per acre. The smaller figures of course apply to suburban parts. The Lower Thames Valley Main Drainage Board was constituted on the basis of the several districts contributing 250 gallons per day per

inhabited house in the district, which, at six people to the house, represents 40·2 gallons per head.

In designing new sewers for Edinburgh, the rule adopted was to provide for a discharging capacity equal to 42 gallons per head per diem (allowing for two inches of rainfall), one-half passing off in eight hours. The capacity of the sewers under these conditions has not been overtaxed.

When the volume that the sewers have to deal with has been calculated, it is usual to estimate that about half the maximum daily flow will have to be carried off in about six hours, or about 8 per cent. per hour, but this of necessity will vary with the conditions of the district sewered. For instance, the tributary sewers of a large town will deliver their sewage into an arterial system at times varying with their proximity to, or remoteness from, the main sewers, and also with the gradients. In other words, an arterial sewer may be compared to a main line of railway which can serve a succession of trains from branch lines if they follow each other at intervals, and do not come with a rush.

Taking half the maximum daily flow as passing off in six hours, the sewer should be calculated so that with this volume it would run about two-thirds full.

It is necessary to obtain sufficient velocity of flow to cause the solid suspended matters to be carried onwards. The following useful observa-

tions of bottom velocities were made by the late Mr. Beardmore :—

30	feet per minute	will not disturb clay with sand and stones.
40	,,	will move along coarse sand.
60	,,	will move fine gravel size of peas.
120	,,	will move rounded pebbles 1 inch diam.
180	,,	will move angular stones $1\frac{3}{4}$ inch diam.

These have led to the opinion that in a large sewer a velocity of $2\frac{1}{2}$ feet per second should be obtained when it is running one-third full, $2\frac{3}{4}$ feet per second running one-half full, and 3 feet per second when running three-quarters full, to make the sewer self-cleansing, that is, to enable the sewage to carry forward the solid matters that would remain deposited with a less velocity. The velocity should at no condition of flow be less than 2 feet per second.

The bottom velocity is that which cleanses the sewer of deposits. The velocity of the surface sewage is the greatest, and of the bottom layer is the least. This is sometimes taken in the proportion of 3 to 5, with a mean of 4. It must, however, be remembered that this cannot be a constant relation, inasmuch as the bottom velocity will be greater with a shallow flow than with a deeper flow, owing to the fact that the velocity at the surface of the former will be greater than it would be if the sewage flowing at that level had a volume above it. The difference between the mean

velocity and the bottom velocity is greater, therefore, as the depth of sewage increases, or, in other words, is greater with a deep flow than with a shallow one.

Where a sewerage system has to be designed to meet the future requirements of a district which at the outset is only partially developed, the volume that will be delivered into the sewers at first will be only a fractional part of that which the sewers will have ultimately to carry. Where these conditions exist, provision must be made for automatically flushing the sewers, otherwise they will become cesspools. Where dead ends are unavoidable, care should be taken to flush them to prevent deposits forming. Although sewer air will be offensive, even when a system of sewers is free from foul deposits, it is better for it to escape and be diluted by admixture with the outer air than for it to be confined in the sewers. What is required is a constant change of air in the sewers. This is produced to some extent naturally by the rise and fall of the sewage at periods of maximum and minimum flow. Where possible, it is most desirable to effect a movement of air in the sewers by means of pipes carried up trees, sides of houses, or into factory chimneys. Where this can be done the ventilating outlets in the roads would not let out foul air but would become inlets for fresh air.

When sewage has to be pumped to distant

points the rising main should be calculated, so that the velocity of sewage flowing in it is sufficient to prevent the solids depositing in it.

Where sewage is discharged in tidal water with the outfall either wholly or partially tide locked at high tides, provision has to be made for storing the sewage until the tide falls. In cases where such an outfall sewer receives storm water the storage chamber may be a very costly work. An alternative method of dealing with this temporary excess is to lift it by centrifugal pumps the few feet necessary to discharge it above the top of the tide when there is a coincidence of a high tide and a heavy rainfall. Such an arrangement, however, requires to be worked almost automatically, as the coincidence may happen only once a year, and then in the middle of the night.

In designing a sewerage system, consideration must be given to the ultimate destination of the sewage, and a calculation of the volume of sewage that the sewers will have to receive, having due regard to the admission or exclusion of the bulk of the rainfall, and so as to minimise pumping.

Sewers should be laid in straight lines and with true gradients from point to point, and at each change of direction there should be either a manhole or a lamphole to the surface at about 100 yards apart, for the purposes of inspection, ventilation, removing obstructions, and flushing. The sewage should be carried through these in a curved channel.

A sewer should, if possible, be laid in the middle of a road within 100 feet of the houses to be drained, to enable house junctions to be made with equal facility, and these junctions should be curved in the direction of the flow.

A tributary sewer or drain should not join a main sewer at its invert, but with a fall to prevent the sewage in the smaller sewer being headed back with consequent risk of deposits forming. If the tributary sewer joins at a higher level it should be by a tumbling bay consisting of a series of steps formed to break the fall.

A system of sewers should if possible be connected throughout to produce the best circulation of air, and to avoid dead ends.

House junctions should be left as the sewers are laid (the positions being carefully recorded), and these should be closed till used, to prevent the admission of subsoil water to the sewer.

When the surface water from roads, &c., is admitted to the sewerage system, the position of gullies requires to be well arranged to avoid flooding the roads during storms.

If the gradient of a sewer is too flat to ensure a self-cleansing velocity, artificial flushing must be provided for either by penstocks in the sewer, or by automatic flush tanks connected with it, similar to the provision made where a sewer is laid in a partially developed district by which in the first

years of its use the volume of sewage passing into it is only a part of that which it is designed to carry ultimately, as already stated.

The Model Bye-Laws issued by the Local Government Board in 1877 state that "no drain shall pass under any building except where any other mode of construction may be impracticable." This is relied on in support of combined drainage, although it refers to the avoidance of drains under a house where they can be laid along a passage.

Combined back drainage consists of a drain which receives the sewage from several houses and conveys it to the public sewer.

The owner of any house drained on the combined system may do something which causes interference with the common drain, thus affecting injuriously some other house. Where each house has a separate drain the owner can more readily deal with any difficulty (such as obstruction, flooding, &c.), than where he is connected with a combined system. It has been held that a combined drain is a public sewer maintainable by the public authority. This decision involves the acceptance by the authority of combined drains, however badly constructed, and an amendment of the law appears necessary in the interests of the ratepayers, who are thus paying the cost of remedying jerry builders' bad work.

Stoneware pipes can be used for sewers up to about 15 or 18 inches in diameter. Beyond that

size sewers are generally made of brickwork, as the handling and jointing of pipes of large size results in their costing as much as brick sewers. Stoneware pipes should be made of good vitreous material having a clear ring when struck, and having strength to stand shocks and strains. They should be well burnt at a high temperature with a salt glaze which permeates the body of the pipe and renders it impervious. They can be tested for impermeability by closing the lower end and filling the pipe with water. Any lowering of the water will disclose defects. By drying a pipe and weighing it, and putting it in water for a while and re-weighing it, a test can be made of impermeability.

The joints of ordinary stoneware pipes should be carefully made so as to be watertight. This requires certain well-known conditions to be enforced. The bed has to be prepared on which to lay the pipes, with spaces taken out to receive the socket, so that the whole length of the barrel is supported. Where the ground is not thoroughly sound and solid, a bed of cement concrete (about 6 inches thick) should be laid at the bottom of the trench, with similar spaces for the socket. This layer of concrete can be carried up after the jointing is finished, so as partly or wholly to encase the pipes, according to circumstances. After the end of one pipe has been placed in the socket of the other it should be butted home and

tarred gaskin caulked up to the face. The joint is then completed by filling the space with cement finished off neatly by a fillet outside. Either neat Portland cement or half clean sharp sand and half cement can be used, but not clay. A properly made joint depends first on the pipes butting home, then on the gaskin being caulked up to the face of the socket, and lastly, on the ring of cement being of equal thickness all round. There is no work that requires more skill in carrying out, or more watchful supervision.

There are means of jointing stoneware pipes other than the ordinary way which has been described. The earliest departure was the Stanford joint, which was formed by the contact of two conical surfaces cast outside the ends and inside the sockets of the pipes. The surfaces when in contact were relied on to make a watertight joint, and were found of service where sewers had to be laid in ground with much water. Such joints require the sewer to be much supported, as any settlement draws the joint. Improvements have been made on this by casting the ends of the pipes with annular rings on both spigot and faucet. These can be filled with liquid cement poured in through holes in the top without risk of its being washed out or disturbed as is the case with ordinary cement joints. The "Hassall" was the first joint based on this principle, and it has been largely used with good results. Other joints with

the same object in view have been designed by Sykes, Doulton and Archer.

A stoneware pipe sewer (and house drain) should be well supported on a bed of concrete wherever the ground is not sound, as no settlement or disturbance, either vertically or laterally, must occur. Where the ground is very bad, and much concreting is required, it is often best to adopt iron pipes. The cost may be greater, although this is not invariably the case, but the result is more certain.

In the construction of brick sewers, only well-burnt and well-shaped bricks should be used, and they should be well soaked to prevent their absorbing the water from the cement. The sewer invert should have a smooth and hard surface to diminish friction, and to prevent erosion. Blue Staffordshire bricks, glazed fireclay bricks, or hard blocks well glazed on the surface, are generally used for inverts. The bricks should be radiated to suit curves so that no more mortar is used than is necessary to make the joint. The mortar should be made of one part best well-seasoned Portland cement to one of clean sharp sand. Good hydraulic lime or blue lias lime is sometimes used. The materials require great care in selecting, and the mortar should be used as soon as mixed. Brick sewers are sometimes built in sections in wooden moulds.

The internal dimensions of egg-shaped sewers are generally determined as follows :—

If D = internal depth of sewer (i.e. from crown of arch to surface of invert);
R = radius of crown of sewer;
r = radius of invert of sewer;
x = radius of sides of sewer (i.e. the curve joining the crown and invert);

then

$$D = x;$$
$$R = \frac{2\,D}{3};$$
$$r = \frac{D}{3}.$$

The oval culverts referred to in the diagram at the end of the book are of this form.

In some cases r is taken at $\frac{1}{8}$ of D, where the sewer has to convey at times only a very small volume of sewage, as the contraction of the invert tends to prevent deposits by increasing the depth of sewage, and consequently improving the velocity. If the volume of sewage is subject to great fluctuation, so that at times it is very small, the egg-shaped or oval sewer is preferable to the circular. As the velocity varies as the square root of the section divided by the wetted perimeter it diminishes greatly with the depth of the sewage flowing. In dry weather there will be the minimum volume and the maximum solid suspended matter, so that it is desirable then to have the maximum depth and scouring effect. Where the sewage generally half fills the

sewer, the oval shape loses this advantage, and the circular shape is cheaper to make, whilst it is stronger.

The thickness of sewers varies with the size, the nature of the ground, and the depth. A $4\frac{1}{2}$ inch ring of brickwork suffices for the smaller sizes in good ground. In larger sewers the thickness varies from 9 inches upwards. The thickness can be calculated by the formula

$$\frac{D \times R}{100} = \text{thickness of brickwork in feet,}$$

where D = depth of excavation and R = external radius of sewer.

Where the nature of the ground requires it, a brick sewer should be strengthened by partly or wholly encasing it with cement concrete; and if there are several rings of brickwork a "collar joint" of cement about an inch thick between each ring ensures the watertightness of the work. The joints of brickwork should not be too thick, the faces being not more than $\frac{1}{4}$ of an inch apart. The trowel should be passed over the mortar to increase its density. The work ought not to be exposed to contact with water until it is well set. In very wet ground a subsoil drain should be placed under the trench to take away the water to the pumps, instead of its running at the bottom of the trench to the pumps. If the sewer is made where any settlement of build-

ings may occur, great care should be taken to well timber the trenches, and even to leave the bulk of the timber in, rather than to run the risk of subsidence.

Some very good sewers have been made entirely of concrete consisting of six parts gravel and sand free from earthy matter to one part of Portland cement. The invert of the sewer is first built, then concrete is well rammed behind a mould with a smooth surface (formed of sheet zinc or other materials) and the top of the sewer is turned upon centres. If the interior is well rendered with cement a good sewer can be made, provided the best well-seasoned cement and perfectly good materials are employed; otherwise, concrete is liable to crack.

CHAPTER IV.

FORMULA FOR FLOW IN SEWERS.

In the author's book on 'Hydraulic Power and Hydraulic Machinery'* the question of the flow of water in open and closed channels is fully entered into, and formulæ are given which were arrived at by Mr. Edgar Thrupp, the author's chief assistant, based on the results of experiments of his own and of a great many observers made during the last forty years and up to the present time.

Temperature has an influence on the flow of water, but it may be neglected in general practice. The following formula and coefficients apply to a temperature of 50° F.

$$V = \frac{R^x}{C \sqrt[n]{S}};$$

where

V = the mean velocity in feet per second;

R = the hydraulic radius in feet; i.e., $\frac{\text{area of water}}{\text{wetted perimeter}}$;

* Chas. Griffin & Co., London, 1893.

S = the cosecant of the angle of inclination of the hydraulic gradient $= \frac{\text{length}}{\text{head}}$;

C = a coefficient representing the roughness of the surface.

The index x, the root n, and the coefficient C depend on the nature of the surface of the channel.

For brick sewers in good condition the value of the index $x = \cdot 61$, $n = 2$, and $C = \cdot 007746$.

For cement rendering $C = \cdot 004$, $n = 1 \cdot 74$, and $x = \cdot 67$.

The formula for brick sewers therefore becomes

$$V = \frac{R^{\cdot 61}}{C\sqrt{S}}.$$

It may be useful to some to work out a case. Applying the formula to a brick sewer 3 feet in diameter, and with a fall of 1 in 1000:

1st. Running full:

$$V = \frac{\cdot 75^{\cdot 61}}{\cdot 007746\sqrt{1000}}$$
$$= 3 \cdot 42 \text{ feet per second.}$$

The discharge from the sewer will be the product of the velocity and water area, which for the sewer running full (the area of water being $7 \cdot 0686$) is

Discharge $= 3 \cdot 42 \times 7 \cdot 0686$
$= 24 \cdot 2$ cubic feet per second.

2nd. Running $\frac{3}{4}$ full :

$$V = \frac{\cdot 905^{\cdot 61}}{\cdot 007746 \sqrt{1000}}$$
$= 3 \cdot 84$ feet per second.

Area of water in a 3-foot sewer $\frac{3}{4}$ full $= 5 \cdot 6866$.

Discharge $= 3 \cdot 84 \times 5 \cdot 6866 = 21 \cdot 8$ cubic feet per second.

3rd. Running $\frac{2}{3}$ full :

$$V = \frac{\cdot 873^{\cdot 61}}{\cdot 007746 \sqrt{1000}}$$
$= 3 \cdot 75$ feet per second.

Discharge $= 3 \cdot 75 \times 5 \cdot 0058 = 18 \cdot 8$ cubic feet per second.

4th. Running $\frac{1}{2}$ full :

V = (same as full) $= 3 \cdot 42$ feet per second.

Discharge $= 3 \cdot 42 \times 3 \cdot 5343 = 12 \cdot 15$ cubic feet per second.

If the sewer was of cast iron the same formula would of course apply, but the coefficients would be different. Thus for new cast iron $C = \cdot 005347$, $n = 1 \cdot 85$, $x = \cdot 67$. For old cast iron $C = \cdot 017115$, $n = 2$, $x = \cdot 66$.

The discharge from a circular sewer running full can be determined by the following formula :

$$Q = \frac{D^{x+2}}{P \sqrt[n]{S}};$$

Where

Q = discharge in cubic feet per second ;
D = diameter in feet ;
P = coefficient in the place of C in the formula for velocity.

The 2 added to x in the index of D is due to the variation of the area being in proportion to the square of the diameter.

The relation between P and C in the two formulæ is

$$P = C \times \frac{7}{88} \times 4^{(x+2)}.$$

The coefficient P has a value ·022965 for brickwork in good condition. For cement rendering it is ·012891. For new cast iron it is ·01723. For old cast iron it is ·03353.

A diagram is given at the end of the book by means of which the velocities and discharges from circular and oval sewers can be directly read. It is plotted from the above formula, the horizontal scale representing log S and the vertical scale log Q. The natural numbers are, however, written against

them. One set of sloping lines refers to the dimensions of culverts, the other set to the velocities of flow.

Applying the diagram to the case of the 3-foot circular sewer with a gradient of 1 in 1000 running full, the diagonal line with 36 inches against it in the column of diameters of circular sewers should be followed until it meets the vertical line marked 1000. The diagonal line for velocity passing through this point will be found to read a little over 3·4 (as compared with 3·42 by the formula), and the horizontal discharge line reads a little over 24 on the scale of discharges for circular sewers (as compared with 24·2 by the formula.

For egg-shaped sewers, the diagram is used in the same way, but the internal height must be found in the column of heights of oval sewers, and the discharges read on the vertical scale of discharges for oval sewers. Thus for a 4-foot oval sewer with a gradient of 1 in 1000, the velocity is 3·52 and the discharge 29·0 cubic feet per second.

The various hydraulic radii are also marked against the sloping lines, so that the velocity in a culvert of any shape may be found from the diagram when the hydraulic radius is known.

For ascertaining the velocity and discharge when the sewer is *not* running full, four graduated scales are given at the bottom of the diagram.

The velocity and discharge having been found

by means of the diagram for any particular sewer running full, these scales supply a means of obtaining the discharge and velocity, by direct measurement on the diagram, when the sewer is running at any given depth of flow. Thus, to find the discharge from the 3-foot circular sewer in the example given above, when running say $\frac{1}{4}$ full, measure (with a pair of dividers) the distance from the arrowhead to ·25 ($\frac{1}{4}$) on the scale of modifications for discharges—circular culverts. This distance must then be set off from the point on the vertical scale corresponding to the discharge when running full to arrive at the required discharge.

In the example, the distance will be set off from 24·2 downwards to 3·4 cubic feet per second.

The scale of modifications for velocities is applied in a similar manner to the (inclined) scale of velocities on the diagram, the measurements being set off down to the right or up to the left according as they are taken from the – or + side of the arrowhead.

In the example, the distance will be set off from 3·42 downwards to the right to 2·48, which is the required velocity in feet per second. Similarly, when the same sewer is running ·6 full, the velocity is 3·67 feet per second.

For the 4-foot oval sewer running $\frac{1}{4}$ full the velocity is 2·52 and the discharge 3·3, the scales for oval sewers being used.

The cases when the distance has to be set off upwards are as follows:—

Circular sewers running at depths between full and $\frac{1}{2}$ full for velocities, and between full and ·83 full for discharges.

Oval sewers running at depths between full and ·57 full for velocities, and between full and ·875 full for discharges.

CHAPTER V.

RIVER POLLUTION.

The Public Health Act of 1875 states that nothing in the Act shall authorise any local authority to make or use any sewer, drain, or outfall, for the purpose of conveying sewage or filthy water into any natural stream or watercourse, or into any canal, pond or lake, until such sewage or filthy water is free from all excrementitious or other foul or noxious matter, such as would affect or deteriorate the purity and quality of the water in them.

The Rivers Pollution Prevention Act of 1876 prohibits the passage of sewage into streams, and enacts that it shall be an offence to continue the pollution. In determining whether or not such an offence has been committed, a marked distinction is drawn between the cases in which the sewage is conveyed into the stream along channels, the construction of which had not been commenced at the time of the passing of the Act, and those in which it is so conveyed along channels then already existing, or in process of construction. In the former case, it will be an offence against the Act for any

sanitary authority to cause or permit the discharge into any stream of any solid or liquid sewage matter. In the latter, an offence will not be deemed to have been committed if it can be shown to the satisfaction of the court having cognisance of the case that the *best practical and available means* are used to render the sewage harmless. The words in italics involved difficulties which caused the Act to be practically inoperative.

The late Mr. Michael, Q.C., in a discussion upon a paper read by the author at the Parkes Museum in 1885, said, "The difficulty in applying to the authorities to carry out the law is that they are the very persons who are the greatest offenders. A small local authority in a district is most likely interested in polluting a river by the refuse of manufactories, and it is called upon to institute proceedings against itself. 'Quis custodiet ipsos custodes?' You can never get any good until an authority is so constituted as to take under its charge the whole great features of the case, until some county or river authority of sufficient extent is appointed with ample powers."

The pollution of some rivers is mainly due to manufacturing refuse which can be, to a very great extent, avoided by previous treatment of the refuse without involving an unreasonable cost to those who cause the pollution. As regards the standard of purity to be attained before discharging a liquid

into a river, it is difficult to arrive at an agreement that will apply fairly to all rivers.

The words "poisonous," "noxious," or "polluting" solid or liquid matter fail to define that which causes injury to fish. The late Frank Buckland objected to these words in considering the way that polluting matter affected fish, and he pointed out that a fish is influenced by pollution more through the medium of the gills than through the stomach. An animal destroyed by prussic acid may be said to be poisoned, but fish are destroyed more by suffocation, the gills being always found to be the structure mostly affected. He noticed that a fish poisoned by pollution, generally speaking, died with the gills and mouth widely extended, as if it were gasping for breath, the gills being the mechanism by which oxygen is absorbed from the water.

A distinct advance was made by the passing of the Local Government Act of 1888 which gives County Councils power to enforce the Rivers Pollution Prevention Act, 1876, and which enables the Local Government Board to issue provisional orders to form joint committees representing interests affected, and investing them with the powers of the Rivers Pollution Prevention Act, 1876, to deal with any river or part of it.

Under the powers conferred by section 14 of the Act of 1888, the Mersey and Irwell Joint Committee was constituted in 1891, and more recently a similar

board has been formed for the whole of the rivers in the West Riding of Yorkshire. In 1893 the following important amendment was enacted in explanation of section 3 of the Rivers Pollution Prevention Act.

"Where any sewage matter falls or flows or is carried into any stream after passing through or along a channel which is vested in a sanitary authority, the sanitary authority shall, for the purposes of section 3 of the Rivers Pollution Prevention Act, 1876, be deemed to knowingly permit the sewage matter so to fall, flow, or be carried."

The Mersey and Irwell Joint Committee obtained an Act in 1892 which gave them a simpler form of procedure than under the Act of 1876, and conferred on them the power to fix a specific time within which sewage disposal works should be undertaken. In 1894 the Conservancy Board for the West Riding of Yorkshire obtained an almost similar Act.

This recent legislation indicates the course that can be adopted in other places with a view to speedily cure the long-felt evils of the pollution of streams and rivers, not only by sewage, but by manufacturing refuse, the admission of which in an unpurified state into sewers often greatly increases the difficulty of dealing with sewage at outfall works.

Section 7 of the Rivers Pollution Act of 1876 is as follows :—

"7. Every sanitary or local authority having sewers under their control, shall give facilities for enabling manufacturers within their district to carry the liquids proceeding from their factories or manufacturing processes into such sewers :

"Provided that this section shall not extend to compel any sanitary or other local authority to admit into their sewers any liquid which would prejudicially affect such sewers, or the disposal by sale, application to land, or otherwise, of the sewage matter conveyed along such sewers, or which would from its temperature or otherwise be injurious in a sanitary point of view :

"Provided also, that no sanitary authority shall be required to give such facilities as aforesaid where the sewers of such authority are only sufficient for the requirements of their district, nor where such facilities would interfere with any order of any court of competent jurisdiction respecting the sewage of such authority."

There are doubts as to the interpretation to be put on this section. In a recent case a sewerage scheme for Elland (on the river Càlder), proposed to provide for 500,000 gallons a day of manufacturers' refuse, the town itself having a population of 10,000 persons. The Local Government Board, after an inquiry, made the following communication to the authority on the 28th June, 1894:—

"With regard to the proposed works of sewerage

and sewage disposal, the Board observes that in addition to the ordinary domestic sewage, estimated at twenty gallons per head of the population, it is proposed to receive into the sewers trade refuse from manufactories, estimated at fifty gallons per head. The Board are advised, however, by their chief engineering inspector, that this course is very undesirable, as the reception into their sewers of such large quantities of refuse, the character of which will vary from hour to hour according to the number of factories which are discharging their refuse at any time, will render almost impossible the proper purification of the sewage at the outfall, and the treatment which may be successful for this purpose at one time may utterly fail at another. The Board would therefore suggest that the local board should consider the desirability of taking steps to prevent the discharge of unpurified trade refuse into the sewers."

It may be mentioned that in Wolverhampton manufacturers are compelled to treat their waste-water before it leaves their works, and this should become more the rule.

Flood waters have been hitherto relied on to cleanse the beds of rivers that have had refuse from manufactories or towns thrown into them. The prevention of the pollution of rivers, however, would enable flood waters to be utilised by storage for the purposes of compensation to millowners and riparian

proprietors, by which the abstraction from a river of pure water for domestic purposes would not entail, as it often does, the obligation to store it also for compensatory purposes at great cost.

Dr. Percy Frankland, in a paper at the Parkes Museum in August 1895, referred to some observations he had made over a distance of 40 miles on the river Dee, where sewage was discharged at various points of its flow. He showed by the rise and fall of the number of microbes in the water at various points in the river, that although repeatedly polluted, it was as repeatedly restored to a state of bacteriological purity.

He also referred to the effect of sedimentation upon water taken from rivers and stored in reservoirs. His observations proved the value of such storage on account of the remarkable removal of micro-organisms which takes place in the process. Experiments that he had made with Thames water indicated that the adequate storage of water diminishes the risk of pathogenic germs, which may have been originally present, remaining in suspension, after subsidence had taken place.

He experimented on examples of the three most representative types of water supply, namely, the Loch Katrine water for Glasgow, the chalk well-water of the Kent Company, and the Thames water as abstracted from the river by the London companies, with the following results :—

The typhoid bacilli which had been introduced into—

(1) Thames water which had been previously sterilised by heat, remained alive for upwards of 32 days;

(2) Loch Katrine water which had been previously sterilised by heat, remained alive for upwards of 51 days;

(3) Deep well water which had been previously sterilised by heat, remained alive for between 20 and 32 days.

On the other hand, the typhoid bacilli which had been introduced into—

(*a*) Thames water in its natural unsterile state, remained alive for 9 days;

(*b*) Loch Katrine water in its unsterile state, remained alive for 19 days;

(*c*) Deep well water in its natural unsterile state, remained alive for 33 days.

The destruction of the pathogenic germs by the other germs is apparently caused either by the latter consuming the food which the former require, or by the production by the latter of that which destroys the former. It has often been thought that the former are devoured by the latter.

Dr. Percy Frankland does not favour the "devouring" theory from the fact that in the deep well water in which the vitality of the typhoid bacilli was the most prolonged, the common water bacteria

multiplied far more extensively than did those in the Thames water, whilst in the Loch Katrine water not only did no multiplication of the bacteria take place, but they actually declined in numbers. Whatever is the cause, the beneficial result remains established that these disease germs have to face conditions in running streams, or storage reservoirs, which are most unfavourable to their existence and propagation.

These experimental observations indicate that the Thames water, having already supported countless generations of water-bacteria, there exists an accumulation in these waters of chemical products which are prejudicial to the typhoid bacillus. On the other hand, the deep well water is in its natural condition not only practically free from bacteria, but it has, in its previous history, had no contact with micro-organisms, and hence it does not either contain any of those bacterial products which are present in surface waters, such as the Thames, which appear to be so antagonistic to the vitality of the typhoid bacillus.

In giving evidence before the Commission on London water, Professor Ray Lankester pointed out that the bacteria which are most destructive of organic matter, and therefore of other bacteria, and of the products of bacteria, are the aërobic. The last stages of the breaking down of these organic matters must be accomplished in the presence of

oxygen, and this is what takes place in a well-aerated flowing river.

His conclusions were deduced not only from examinations of the Thames water, but of the material filtered off from the water, which represents that which is contained in large volumes of it. He found that three-fourths of the bacteria were carried down by subsidence, and this indicated the safety of storing large volumes of river water, even if it contained bacteria.

By the addition of sufficient lime to precipitate the carbonate of lime in solution (as in water softening processes) he considered the complete removal of bacteria would be effected; as cream of lime is one of the best destructives of typhoid dejecta. He also stated that bacilli multiply to a far greater extent in pure than in impure water, and this would result in greater mischief if a perfectly pure supply were accidentally polluted. This is evidenced by the pollution of what he called the "water of excessive purity" at Caterham by typhoid dejecta, which caused the well-known outbreak there.

If a sewage effluent that is discharged into a river contains suspended matter which can subside, the oxidising action of the river is limited to the mere surface of the deposit, leaving the part beneath to ferment, and thus to be injurious to health by liberating sulphuretted hydrogen and other gases; whereas if the suspended matter is removed, and

only dissolved matter passes off, the oxidising action of the free oxygen in a running stream is able to attack and destroy the whole, and to convert the organic matter in solution into harmless substances.

The author is the last to under-estimate the importance of preserving water supplies in the purest possible condition, but he wishes to combat the merely sentimental part of the case, which at times may lead to the imposition of grave burdens on communities in regard to water supply. No efforts should be relaxed to prevent the streams from being employed as vehicles for carrying off sewage or manufacturing refuse. The standard of purity should be maintained high, both from a sanitary and æsthetic point of view. This applies equally to canals, many of which now constitute serious nuisances.

CHAPTER VI.

DISCHARGE INTO THE SEA.

If a town is situated close to the sea it is sometimes considered to be in a more advantageous position than inland towns respecting the disposal of sewage, as it has only to be discharged into the sea. That is not a safe assumption, as the experience of many watering-places proves.

In the Local Government Board Bluebook of 1876, one of the conclusions arrived at is as follows: "That towns situate on the sea-coast or on tidal estuaries may be allowed to turn sewage into the sea or estuary below the line of low water, provided no nuisance is caused; and that such mode of getting rid of sewage may be allowed and justified on the score of economy." It would have been better to have further indicated the conditions which require to be complied with to prevent a nuisance, as it will be found that in a great number, if not the majority, of cases the conditions do not exist. To avoid a nuisance the sewage must be discharged into the sea at a point not only below low water, but where there is a well-ascertained

current which will carry it permanently seaward. A point of discharge complying with these conditions cannot always be found, and requires to be ascertained by careful tidal and other observations.

Sewage having a higher temperature and a lower specific gravity than sea water, rises to the surface. If it is not carried seaward quickly, part of the suspended solid impurities are likely to be deposited on the coast, whilst the rest of the suspended impurities float on the surface and are carried backwards and forwards by every tide, either decomposing and liberating offensive gases, or causing a serious annoyance to those who may have occasion, from business or recreative purposes, to be afloat.

In some cases, by means of long outfall sewers, the sewage is carried away from the place producing it to the sea, but they are frequently simply transferring the refuse to others, the tide carrying it so as to cause mischief and nuisance elsewhere.

These outfall sewers require careful ventilation, as the sewer gases are otherwise liable to be forced back into the town sewers at high tides, or after storms, often causing foul smells to come up through gullies and open gratings, as well as into the houses, even if the house drains are trapped from the main sewer.

In order to determine whether the sewage at a proposed outfall will or will not be carried away seaward, some very simple tidal observations can be

made. If floats are thrown in at the point of proposed discharge, at ebb and flood, spring and neap tides, an observer can ascertain fairly well by the behaviour of these floats whether the current is always seaward. Care must be taken to have the float submerged sufficiently, and to have the visible portion small enough, to prevent the direction of the float being affected by winds, which would tend to divert the floats from the real directions of the tide.

CHAPTER VII.

IRRIGATION.

The purification of sewage by its utilisation on land should be carried out in view of the investigations which have been made of late years by chemists and bacteriologists (referred to in detail under the head of Filtration), as a consideration of the data thus afforded points to the necessity for better methods than have been hitherto adopted on sewage farms.

It is now clearly established that the changes that have to take place in sewage to effect purification, or that are necessary to enable the manurial ingredients in it to be best adapted to the requirements of plant life, are due to the nitrifying action of micro-organisms. It is essential that the conditions should be adhered to which favour the cultivation of these bacteria, and the operations carried out at many sewage farms will have to be revised to meet these conditions. Where the land under treatment is open and pervious, the most solid part of sewage, as well as the dissolved and finely suspended organic matters, admit of being

liquefied in the interstices of the soil, and of being converted into the harmless nitrates and nitrites which are so beneficial to plant life. Where the land is impervious this can only be partially effected, and in such cases the liquefaction of the solids by bacteriological influences has to be brought about by methods that are described elsewhere, so that the fluid that is applied to the land is both free from that which would clog the pores, and is at the same time highly charged with the nitrates and nitrites which are available for vegetation. If they are not required by the crops they are in a form that can pass away without causing pollution or nuisance.

Sewage farming has too frequently been regarded only from an agricultural point of view, whereas it must be treated as a combination of both sanitary and agricultural interests. These two, however, can only be successfully combined where a sufficient area of suitable land is acquired to enable the crops cultivated on it to receive the sewage only when they want it, at the same time that the sewage is purified on other areas when it is not wanted by crops. When this cannot be accomplished, the agricultural part of the matter must be disregarded, and the filtration and purification of the sewage as a sanitary necessity should be alone kept in view.

The reason why sewage farming has been so unduly pressed and advocated is, that in the early days of sewage utilisation, those who directed public

opinion on the question came to the conclusion that the full chemical value of sewage could be realised by its application to land.

The fertilising value of sewage, on which so many erroneous expectations have been based, has been proved to be seriously reduced to the sewage farmer by the fact that for sanitary purposes sewage must be disposed of day by day throughout the entire year, and that the volume to be disposed of is generally greatest when it is absolutely injurious to the crops.

As the ammonia in sewage diminishes or disappears with the distance travelled before it reaches the outfall, it is important that the interval of time between its production and its utilisation should be short, which points to the necessity for its being delivered as fresh as possible, and this can only be effected where sewerage systems are well designed and properly carried out.

Mr. Warington found that in a clay soil the functions of the nitrifying organisms were confined to the upper eighteen inches, whereas in a sandy soil they would be in active operation at a greater depth. Also that the absence of phosphates adversely affected nitrification.

The application of lime accelerates the process of nitrification, and has been found advantageous to plant life where large volumes of sewage are utilised for irrigation purposes. On the large sewage farms

of Berlin (hereafter referred to) from one to two and a half tons of waste lime per acre have been spread over fields which had previously been drenched with sewage, and the result was most beneficial. The land in this case had a sandy subsoil.

The most unsuitable soils for sewage purification are stiff tenacious clays, peaty or boggy land, and certain conditions of coarse gravelly soils, which contain hard conglomerate layers often very dense and impervious.

Clay lands can be rendered more fitted for filtration by specially preparing the surface to some depth by ploughing or digging in ashes or other materials. These will convert the impervious surface into a more open one through which the sewage can sink, and the nitrifying processes can be set up.

Clayey lands, besides being too dense for sewage to pass through under ordinary conditions (as when wet and waterlogged in the winter months), are liable to crack to considerable depths in periods of long continued dry weather, when unpurified sewage can pass untreated into the subsoil. In many cases clay lands have been deep drained by cutting trenches, laying agricultural drains at the bottom, and filling up with burnt clay, ballast, or other porous material. This has resulted in serious failure, as the crude sewage has passed down the trenches unpurified and away in the underdrains. Where this can possibly

occur the effluent from one area must be passed on to a lower bed for further treatment.

In sewage farming the object is to utilise, and not to waste the sewage. To prepare the land so that it will absorb the sewage uniformly over its surface, without flooding or overflowing, is that which must be accomplished. This can be done by laying out the area in slopes according to the contour of the surface, and according to the nature of the soil. These slopes will vary considerably, and no rules can be given to apply to all circumstances. They must be settled by a careful examination of the conditions, and sometimes by actual trials to determine them. Where the land is impervious the slopes must be flat, otherwise the sewage will pass over without being absorbed. On porous land the slopes should be greater to prevent the sewage being absorbed unequally. The slopes vary from 1 in 20 to 1 in 120.

After the sewage is delivered on to the land at the outfall it is distributed by main carriers, either of earthenware or concrete, or of bricks in cement. These are placed in contour, and are regulated by sluices and stops so as to command the area to be irrigated, the sewage being distributed over the surface by carriers made in the ground. Any pipe carriers underground which convey the sewage from one point to another should be kept low enough to prevent disturbance when the surface

is being manipulated either with the plough or otherwise.

There are several methods for distributing sewage over the surface of land, which are largely regulated by the purposes to which the land is to be devoted.

In the ridge and furrow system the land is prepared in beds with ridges about 40 feet apart, having slopes of about 20 feet on either side with an inclination (according to the ground) from 1 in 50 to 1 in 150, or even more, if the ground is very impervious. The ridges have distributing channels so formed that the sewage flows over them down the slope of the plot or field to the furrow in a uniform layer or film, and any which is not absorbed passes to a lower plot.

The catchwater system is used more for very sidelong and irregular ground. A carrier is laid to command the area to be treated, and the sewage overflows from it at any part by temporarily stopping up the carrier. It then passes to a lower level where a catchwater gutter, made to the contour of the land, passes it over a still lower part of the area. Main carriers vary in size, but are generally about one to two feet wide, and about six to ten inches deep. The fall should be about 1 in 500 or 1 in 600. To properly distribute sewage over an area of land requires considerable care, otherwise the whole area will not be equally

dosed. What has been said elsewhere about underdrains must be borne in mind in arranging filtration areas to deal with as much sewage as possible in order to get rid of it without producing a foul effluent.

Italian rye-grass is one of the best crops for sewage, as its capacity for absorption is enormous, and it occupies the soil so as to choke down weeds, which are a source of trouble and expense on sewaged land. The cultivation of a particular crop must, however, be adopted with reference to the local markets, so as to prevent the loss of the produce. Many excellent and valuable crops are wasted owing to the consumption in the district being less than the supply.

Osiers are very useful plants to absorb the organic impurities in sewage. The American water-weed, anacharis, is a very gross feeder, and will assimilate great quantities of organic impurity. A small area planted with a little of this weed will soon become an excellent purifier of sewage.

There are other plants which are capable of absorbing organic impurities, such as duckweed, sedges, common reed, flowering rush, white and yellow lilies, frogbit, water ranunculus, liverwort and watercress.

Great care is required in conducting investigations, whether chemical or bacteriological, in regard to sewage treatment. The composition of the raw

sewage is continually varying at different times of the day, so that comparisons between the sewage and effluent require to be made in view of this practical difficulty. No reliance should be placed on results in which the chlorine in the effluent differs materially from that in the raw sewage.

It is proposed to refer only to two instances of sewage farming, namely, one of the oldest cases, the Craigentinny meadows near Edinburgh, briefly, and one of the most recent, namely the Berlin sewage farms. The application of sewage to land, and the conditions which govern the whole matter, can be best dealt with in considering the chemical and bacteriological changes which take place. These are fully entered into hereafter, under 'Filtration.' The results of sewage farming at many towns in this country are summarised in a Table on page 65.

CRAIGENTINNY.

The well-known Craigentinny sewaged meadows near Edinburgh are composed chiefly of poor sandy land. Analyses of the soil, after many years of continuous irrigation with large volumes of sewage, prove that the sandy area contains only about 1½ per cent. of organic matter, and this is due solely to root fibres.

The Craigentinny irrigation farm is described by Mr. Fairley, C.E., as having an area of about 236 acres. These meadows were laid out upwards of two hundred years ago, and a part under Italian grass and other crops about fifty years ago. The subsoil varies between a stiff boulder clay and light sands and gravels, the bulk being underdrained with 2-inch and 3-inch tile drains laid ten yards apart and at a depth of 3 feet. The sewage is conveyed along the higher ground by main carriers 5 feet by 2 feet, delivering into secondary carriers 2½ feet by 2 feet, which divide the land up into ¾-acre plots. From these secondary carriers small leaders and turf drains 12 inches by 6 inches are cut, so as to distribute the sewage as evenly as possible over the surface of the meadows. The

effluent is caught by ditches and is used to irrigate the land at lower levels. There are other sewage farms which are not underdrained, and are constantly under grass.

From May until the end of October the whole of the sewage, amounting to 800 cubic feet per minute, is utilised on the land, each group of plots being under sewage about 24 hours once every three weeks. In the winter, irrigation is only carried on during open weather. A small area of clay land not underdrained does not play an important part in the purification of the sewage, the great bulk of the sewage runs over the surface and deposits part of its suspended matter. The presence of these sewage meadows is considered to have a tendency to lower the value of land for building purposes in the immediate vicinity. Although no distinct nuisance may arise from them, their near neighbourhood is not free from disagreeable odours, especially in damp warm weather. These farms are not worked with a view to purify the sewage, but to enhance the agricultural value of this poor land and to produce crops for cow-keepers and dairy farmers.

BERLIN SEWAGE FARMS.

In a paper read at the Institution of Civil Engineers in 1892, Mr. Roechling gives a detailed description of the sewerage of Berlin and of the sewage farms.

The census of 1890 gave the population of Berlin to be 1,578,794, and its density from 220 to 25 persons per acre. The rateable value was 19,182,661*l.* The town is situated on the sandy plains of North Germany, the river Spree running through the centre.

The area of land acquired for sewage farming amounts to about 19,000 acres, of which, however, only 11,000 were utilised in 1890 for that purpose. Of this, 7942 acres were specially prepared and treated with sewage. About 2000 acres were laid out in rectangular plots for grass, from 5 to 6 acres each, subdivided into smaller plots of $\frac{3}{4}$ acre. The rest has been underdrained, and laid out in beds or tanks of from 5 to 22 acres. This acreage is dealt with as four farms, two on the north of the Spree and two on the south. Market gardeners and small farmers rent some of the

land, and in 1889-90, 2224 acres were thus let, of which 1890 acres consisted of sewage-treated land.

The following table shows the respective areas and cost:—

Farms.	Acreage.		Price.	
	Acres.		£	£
Osdorf	3,056		115,357	
Gross Beeren	2,362		43,802	
Total of Southern Farms		5,418		159,159
Falkenberg	2,382		94,208	
Malchow	3,216		192,660	
Total of Northern Farms		5,598		286,868
Total		11,016		£446,027

The average volume of sewage treated on the farms in 1889–90 was nearly 30,000,000 gallons daily, including all storm water. This was stated to be from 7 to 10 per cent. of the total volume, which averages about 23½ gallons per head per day throughout the year.

The sewage is pumped (the lifts varying from 54 to 115 feet) and is distributed from stand-pipes averaging 25 feet high, erected on the highest parts, through cast-iron pipes over the farms. Thence it

is distributed by ditches from 18 inches to 3 feet deep, and again by trenches and furrows to and over the plots.

About 1240 acres represent land permanently occupied by roads, buildings, large ditches, &c., and about 800 acres for small ditches, carriers and embankments, or a total of about 2000 acres non-productive, except in respect of revenue from fruit trees planted along the roads.

The cost of preparing the land was 12*l.* per acre of land actually laid out, or 8*l.* 12*s.* per acre of the whole area.

Description of Work.		Expenses per Acre. Of Land Prepared.			Of Total Area.		
		£	*s.*	*d.*	£	*s.*	*d.*
Distribution of sewage in cast-iron pipes	about	19	0	0	13	10	0
Laying out land	„	12	0	0	8	10	0
Draining land	„	8	0	0	6	0	0
Total	„	39	0	0	28	0	0
Sundry expenses	„		..		4	10	0
Total	„		..		32	10	0
Purchase of land	„		..		40	10	0
Capital expenditure per acre	„		..		£73	0	0

The table preceding gives the capital outlay in laying out and draining the farms.

In the working of the farms, one class of labour employed consists of misdemeanants from the House of Correction, the cost of each being about 6½*d.* per day, and for purpose of comparison it is estimated that seven of these men are equivalent to two free labourers at 1*s.* 8*d.* per day.

The following table gives information as to the average results from 1876 to 1890:—

Average Daily Quantity of Sewage per Acre, Number of Acres per Million Gallons, and Number of People per Acre.

From January 1, 1876, *to March* 31, 1890.

	Number of Gallons of Daily Flow of Sewage per Acre of Land actually treated on all four farms.	Number of Gallons of Daily Flow per Acre of Total Area of all four farms.	Number of Acres for every Million Gallons of Daily Flow of Sewage. All four farms combined.		Number of People per Acre. All farms combined.	
			Acres of Actually Treated Area.	Acres of Total Area.	Per Acre of Actually Treated Area.	Per Acre of Total Area.
Average ..	3374	2004	297	499	142	87

Crops Grown on the Portion of Irrigated Land, together with the Acreage of Irrigated Land Let.

During year.	*Oil-producing Plants*, i.e. seeds used for manufacturing Vegetable Oils, such as Colza, Rape Oil, Oil of Mustard, &c.	*Fibrous Plants*—Hemp.	*Cereals*—Wheat, Barley, Oats, Rye, Indian Corn, Buckwheat.	*Roots and Vegetables*—Potatoes, Beetroots, Turnips, Carrots, Cabbages, Mangolds, Chicory.	*Grass.*	*Sundry Crops*—Seed and Trial Beds, Nurseries, Willow and Alder Beds, &c.	*Total Acreage Farmed* by City Authorities, prepared Land only.	*Acreage Let* prepared Land only.	Acreage not under Cultivation.	Total Area Specially Prepared.
	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.
1887–1888	260·11	..	3,279·41	1,070·52	2,001·33	88·68	6,700·05	1,049·37	79·79	7,829·21
1888–1889	187·91	70·75	2,794·74	1,224·28	1,932·33	76·80	6,286·81	1,579·13	46·79	7,912·73
1889–1890	236·98	1·08	2,817·20	1,012·57	1,785·44	80·45	5,933·72	1,890·18	118·12	7,942·02

Note.—Only the specially-prepared land is under sewage treatment. Legumes (beans and peas) and fodder plants (clover, lucern, lupins, &c.), used to be grown on the farms, but the cultivation of these has been discontinued. The grass grown is a mixture of Italian rye grass and Timothy; it does not stand the winter well, and whole plots have to be resown in spring. Grass plots are usually ploughed up every four or five years. The rotation of crops varies considerably on the different farms. The original division into beds and grass plots has undergone many changes.

The sewage is applied to the land (the sandy nature of which must be kept in mind) at periods varying from once in 11 days to once in 52 days, the average being once in 24 days. The sludge goes on to the land (other than grass plots) with the sewage. Before sewage is applied to grass plots, the sludge is removed in shallow catch-pits, as it is found that the coating of sludge on the plot interferes with the growth of the grass.

The crops and their rotations vary considerably on these farms, and the table on page 61 affords data upon this.

Cereals and oil-producing plants are grown on levelled surfaces, and are only sewaged as long as the crops are underground, and the plant is not brought into direct contact with the sewage. Roots and grass plots are treated with sewage all the year round. The seeds are put in with the drill. Deep ploughing with steam is in use, as it turns the sludge, which remains on the surface of the land after irrigation, as deeply as possible into the ground.

The profits on the management for 1889–90 averaged on all the farms 1·162 per cent. on the capital outlay. If repayment of capital be taken into account, this profit would have been turned into a loss.

The results of analyses of the raw sewage and of the effluents are given in the following table :—

Raw Sewage and Effluent-Water Analyses. *All farms combined.*

(*Expressed in parts per* 100,000.)

Description of Sample.	Dry Residue at 115° Centigrade (Total Solids).	Loss on Ignition. (Organic and Volatile Matter.)	Ash. (Mineral Matter.)	Permanganate of Potash reduced by Organic Matter.	Ammonia Free (NH_3).	Ammonia Organic.	Nitric Acid (N_2O_5).	Nitrous Acid (N_2O_3).	Sulphuric Acid (SO_3).	Phosphoric Acid (P_2O_5).	Chlorine (Cl).	Potash (K_2O).	Soda (Na_2O).	Germs per Cubic Centimetre.	Suspended Matter. Dry Residue. (Total Solids.)	Suspended Matter. Loss on Ignition. (Organic and Volatile Matter.)	Suspended Matter. Ashes. (Mineral Matter.)	Suspended Matter. Phosphoric Acid.
Raw sewage—Average during the year	104·51	31·33	73·18	34·55	12·800		0	0	7·24	2·836	21·85	6·93	22·65	..	113·85	75·49	38·36	1·960
Effluent from grass plots, broad irrigation—Average during the year ..	90·26	11·90	78·36	2·11	0·106	0·039	12·47	0·221	9·45	0·043	16·60	1·81	16·37	20,505				
Effluent from beds, filtration—Average during year	101·39	13·22	88·17	2·57	0·231	0·048	13·97	0·384	9·63	0 055	17·67	2·43	16·66	8·576				
Effluent from tanks, filtration—Average during the year	90·64	13·83	76·81	6·01	1·667	0·109	8·19	0·363	7·16	0·076	16·42	2·50	14·84	0·222				

The following table gives a summary of the results at the Berlin sewage farms for 1889–90.

Number of Gallons of daily flow per acre of total area of farms.	Number of Acres for every million gallons of daily flow of sewage. All farms combined.		Number of People per acre. All farms combined.	
	Acres of actually treated area.	Acres of total area.	Per acre of actually treated area.	Per acre of total area.
2687	268	372	156	112

TABLE OF SEWAGE FARMS IN ENGLAND.

The following table will afford information in regard to irrigation in many towns in England.

Name of Town.	Population.	Daily Flow of Sewage in Gallons.	Annual Rateable Value.		Area of Land Irrigated.	Number of Inhabitants to each Acre Irrigated.
			£	s.	Acres.	
Banbury	12,768	450,000	55,880		155	82
Bedford	31,000	1,000,000	122,254		180	172
Burton-on-Trent	49,084	6,000,000	246,509		362	135
Cheltenham ..	49,000	1,000,000	250,000		360	136
Crewe	35,000	1,378,019	106,039		257	136
Croydon	114,000	4,500,000	687,994		565	201
Derby (West)	40,400	1,100,000	192,402		207	195
Doncaster ..	33,000	700,000	129,759		298	110
Leamington ..	27,000	770,000	168,000		350	77
Norwich	106,000	4,500,000	329,683		309	343
Reading	65,000	1,500,000	300,000		350	185
Rugby	11,262	320,000	64,488	15	73	154
Tunbridge Wells	30,000	800,000	209,000		310	96
Wigan	58,950	1,250,000	175,094		420	140
Wrexham ..	13,500	500,000	54,744		180	75

The author is indebted to the Town Clerks and Borough Engineers for the data necessary for the compilation of these results.

From the preceding table the following averages are deduced :—

149 people to each acre irrrigated ;

170 acres to each million gallons of sewage, equivalent to 5888 gallons per acre.

38 gallons of sewage per head per day.

CHAPTER VIII.

ENSILAGE.

In the application of sewage to land it is important to overcome the difficulty that is often experienced in disposing of the enormous green crops which highly sewaged land can raise. Thus one of the advantages of applying sewage to land cannot be fully realised, as the time of production of the green crops, and the demand for them, not coinciding, they are sometimes to a large extent valueless. Any arrangement, therefore, by which that portion of the produce for which there is no immediate demand can be stored for future use, would be of the greatest service to the sewage farmer. Such a solution of the difficulty is found in the system now known as "Ensilage."

The author acted as the engineering member of Lord Walsingham's Commission on Ensilage, some years ago, and the Blue Book that was issued by the Government as the outcome of that inquiry contains detailed information on this subject. The following brief description will suffice for the purpose of connecting it with sewage farming.

The process termed "ensilage" is the preservation of green crops in a pit, or chamber, called a Silo. All kinds of green crops appear to be capable of being converted into silage, from the finest grass to the coarse stuff that cattle would not otherwise touch. The crop can be cut and siloed in any weather however wet; but it should not be left cut in the field long, as the sooner it is removed and placed in the silo the more likely is it to turn out good silage, and it should be cut before rather than after the plant has attained maturity.

Before describing the several plans which have been tried for producing silage, it may be useful to say a few words about the chemistry of the subject, in order to make the process clear.

If any green crop be left exposed to the air, the fermentation which begins as soon as it is cut, would continue to the putrefactive stage, and the crop would be useless for feeding purposes. This fermentation is produced partly by the active agency of oxygen, and partly by bacteria. The theory of the latter agency is based on Pasteur's elaborate researches, which showed that certain ferments continue their action without the presence of oxygen or atmospheric air. He described it thus:—"The ferments, properly so called, constitute a class of beings having the property of living out of contact with free oxygen gas. One might express the theory in

the concise form—fermentation is the consequence of life without air."

If the green crop, after being placed in the silo, be left freely exposed to the air for a few days, it heats, and if the temperature be allowed to rise to from 125° to 150° F. the bacteria are killed, and the subsequent fermentation which would have been produced by them, is arrested. The resulting material is called "sweet" silage, which remains aromatic, having gone through what is termed a "haying" fermentation. If, on the other hand, as soon as the green crop is put in the chamber, it is subjected to pressure, by which the air is excluded as far as possible, and if the temperature does not rise above 100° F. at the outside, the bacteria live and develope, and the fermentation is greater than before, leading to the formation of lactic or acetic acids, with a loss of some of the saccharine matters, that become broken up and form new combinations which partly pass away as gases. The silage thus produced is called "sour," to distinguish it from that termed "sweet," although the difference does not affect the avidity with which cattle eat it.

The fermenting action which takes place in the silo is partial digestion (such as would have taken place in the animal's stomach), causing a softening of woody fibre, and a preservation of the flesh and fat-producing ingredients of the green crop. The loss

of weight produced by fermentation falls upon those parts of the fodder which have the least feeding effect, such loss comparing favourably with the preservation of grass, &c., by exposure to the sun.

If the silage is to be made from coarse stuff, it is sometimes chaffed, which enables it to be more easily stacked, especially if it is to be piled up any height.

When the crop is placed in the silo it requires to be spread evenly over the floor and trodden down, particularly round the walls. After the silo is full, one plan is to cover the whole surface with a layer of straw or heather, and to lay over this 1½-inch or 2-inch boards weighted to a pressure varying from 70 lbs. to 200 lbs. per superficial foot, by which the air is forced out. After the material has been pressed, the weighting arrangement is removed, and more material is added, to make up the vacant space, and to utilise the full capacity of the silo. This operation may continue for weeks until the silo is filled. A little salt is sometimes added to the material when placed in the silos; but this is not essential, although it is thought by some to be beneficial to the cattle that feed on the silage.

Ensiling has been accomplished without any chamber at all, the green fodder being simply stacked in the open and heavily pressed, the outer parts being, however, exposed to the air.

The construction of silos must depend upon the

circumstances which apply to the place where the green crop has to be converted into silage. An economical form of silo is of course essential where the outlay of capital is a serious consideration.

The best place for a silo is close to the land producing the crop, as well as to the feeding-sheds where the silage is used. A good plan is to place the silo on sidelong ground, so that the green stuff can be put in at the higher, and drawn out at the lower level. A road should be made to both top and bottom. As silage is about three times the weight of ordinary hay, it should be carted the minimum distance. The weight of silage may be calculated by taking fifty cubic feet of capacity as equal to 1 ton.

A pit excavated in ground that will not slip in (or that requires only a very simple support) will suffice, and there are many records of successful earth silos which have been dug out like trenches, about 11 feet at the top, with sloping sides, and of any convenient length. These trenches, when filled with the green crop, are covered up with about 2 feet of earth.

Where, however, the system is to be worked as a permanent institution, some durable structure would be more economical in the long run. Large silos, well made, and with smooth walls, to secure even subsidence, will produce silage with a less percentage of waste than small silos with rough sides. Old

barns, sheds or other buildings (generally found about farmsteads), have been utilised successfully.

About 12 feet is a convenient depth if the silo is not above ground. If it is, then less must suffice, unless mechanical means are available for shifting the material. If it is not liable to be waterlogged, it may be put 5 feet or so below ground; but care must be taken to divert soaks and springs.

A silo too large on the cutting-face involves a large surface in cutting, which means deterioration of a portion of the silage greater than would be the case where it has a smaller cutting-face, in which the silage can be consumed before it is injured by too much exposure after the silo is opened.

In constructing a silo the obvious point to aim at is to enclose the largest cubic space in a water- and air-tight state, with the least wall-expense. The inside of the silo should be made vertical and smooth by rendering it with cement, so that the material will sink with the least friction. The cost of a permanent silo varies greatly. Where the silo is simply a trench dug in the ground it costs only 5*s*. per ton of green stuff. Others made of brick or concrete cost from 15*s*. to 25*s*. and upwards, per ton of green stuff.

In order to economise labour, a good plan is to have more than one silo, and to keep filling them alternately, the material in one being left to settle or be pressed down whilst the other is being

charged. A few feet more can be added until the several silos are full, when the entrance is closed. This is sometimes built up with stone or brickwork, which is pulled down when the silo is opened.

The weighting of the material in the silo has been the subject of many arrangements, such as earth-boxes containing stone, iron rails laid on planks, cases of water, &c. Pressure is most required to protect the upper part of the material, the lower being pressed by the weight of the superincumbent mass.

Mechanical pressure has been applied by several contrivances such as by Potter's hydraulic-jack method, Johnson's (of Croft) lever pressure, and Reynolds' screw-chain pressure.

A useful portable silo is made by Messrs. Reynolds, and consists of a series of jointed boards clamped together by iron belts, screwed up tight and covered by a water-proof canvas, which makes an air-tight and water-tight chamber. The pressure is applied to the top of the silage by means of a screw apparatus and chains anchored to the bottom of the silo and passing over rollers to the chain-tightener. This apparatus is moved from point to point and applied to the several cross beams of the wooden covering. The chains, on being screwed up, exert a pressure of 200 lbs. per square foot, which can be increased or diminished by placing the beams and anchor-chains closer together or

further apart. A man screws up the material once a day or so for about a week, when it ceases to be compressible.

Mr. James Howard constructed a silo 20 feet high, of hard bricks set in cement, and finished off with a channelled stoneware course of tiles. This was closed in with a galvanised-iron roof, the eaves of which dipped into the channel at the top of the wall and formed, with the channel, an air-tight joint, as water always remained in this groove. Before the roof was put on, the silo was filled with unchopped green clover, which was trodden down by boys, and no covering or weighting was employed. The silage turned out fragrant, and had no trace of mould even on the top, where it was not pressed.

The observations which have been made as to the effect of feeding animals on silage are most satisfactory in every way, and there can be no doubt now of the success of the system.

As soon as silage becomes better known it will doubtless be much sought for, and will be transferred to places at a distance from the locality where it is produced, thus extending the field of demand for it.

In some cases discredit has been brought upon silage by farmers trying to make it out of hay that has been exposed to rain until it was nearly spoilt. Putting this stuff into a silo is not the way to make good silage.

CHAPTER IX.

PRECIPITATION.

WHERE sufficient land cannot be obtained for sewage disposal with a view to utilising its manurial constituents, efficient chemical precipitation enables most of the suspended and part of the dissolved organic matters in sewage to be removed. It is not many years since sewage was looked upon as capable of being made a source of profit to the community producing it, by applying it to land by broad irrigation, whilst chemical-treatment speculators also contended for the possession of it as if it were a prize. Local authorities did not, therefore, recognise that efficient measures to get rid of their sewage must, as a rule, involve a permanent burden on the rates.

In order to enable reliable deductions to be made regarding the cost and efficiency of precipitating systems, it is necessary that certain main principles should be laid down at the outset, to serve as a basis on which comparisons can be founded. For instance, the quality of sewage and the number of

the population connected with the sewers, as well as the flow per head, should be kept in view. The cost of the chemicals should be considered, both with reference to the quality of sewage operated upon, and also with reference to the standard of purity of the effluent produced. The bulk and value of the resultant sludge also must not be overlooked.

Considerable advances have been made in increasing the efficiency and simplifying the working of chemical treatment of sewage, and these results have done much to remove the previous difficulties which attended precipitation.

Chemicals as precipitants were once used which had a high fertilising value, the expectation being that they would enhance the manurial value of the sludge. The amount of this material, however, which passed off in solution and was lost, prevented the system from answering.

The results derived from the application of chemicals to sewage, depend a great deal on the construction of the tanks in which precipitation takes place. Where they are too shallow, and the velocity of the sewage through them is too great, the suspended particles, although heavier than the fluid in which they float, are unable to sink by gravitation, but remain suspended long enough to be carried through the tanks by eddies and upward currents. Many precipitation works now in operation have this defect.

Where a considerable part of the rainfall is received into the sewerage system, provision should be made for a tank capacity of about 50 per cent. of the average daily dry weather flow, which will give a workable margin for contingencies. Several small tanks are better than a very few large ones, as there is less risk of difficulties arising when the tanks have to be stopped for cleaning out or for repairs.

In England, shallow tanks (having a depth of about 4 to 5 feet at one end and about 6 feet at the other) are generally used. The bottom should have a fall towards the inlet end to which the sludge can be swept with facility. The tank is emptied by means of a floating arm which falls, on drawing off the supernatant water, and ensures its being taken from the upper layer of fluid in the tank. A valve controls this drawing off, so that as soon as there is any appearance of floating matter in the water being let off, the valve is closed and the sludge remains.

The vertical tank, as it is termed, has recently attracted much notice, and is described hereafter in dealing with the sewage works at the Dundrum Asylum in Ireland. The same plan was adopted at Chicago, where the Kinebühler tank was employed.

With some processes it is better to have the tanks designed so that they are worked intermittently, by which a period of rest is allowed for

the solids to precipitate. The continuous working, however, is more generally adopted.

A recent arrangement of tank by Mr. Frank Candy deserves mention. The bottom of the tank is made flat, and in the centre is pivoted a horizontal perforated pipe which reaches to the side of the tank. This is pivoted on another pipe, which is carried up to within a foot or two of the full water-level of the tank, and at that point the sludge is discharged without pumping. The pivoted pipe is revolved by hand from the outside of the tank when it is being cleaned. The perforations in the pipe being on the under side of it, and only a few inches apart, and the pipe itself being but a little above the bottom of the tank (enough to clear it), the rotation of the pipe covers the bottom, and the sludge is drawn, or sucked away, from the whole of the surface. The pressure of water in the tank forces the sludge through the connecting pipe, and out to a higher level, whence the sludge can be run into a sump. The perforations in the pipe are larger than the space between the bars of the screening grid. The sludge produced is thicker, and therefore of less bulk than the sludge usually drawn from other precipitation tanks. The removal of the sludge by this arrangement does not interfere with the flow of the sewage into the tank, and when the tank is started its working is continuous.

LONDON.

The census of 1891 gave the population on the north side of the Thames at 2,687,084, and on the south side 1,523,972, or a total of 4,211,056. In 1857 it was calculated that the population in about 40 years would be 3,448,500, but it has already exceeded that estimate, and by the end of the century it is probable that nearly 5,000,000 people will be contributing to the metropolitan sewage. The estimate originally made (which is referred to elsewhere in dealing with sewerage) was that there would be a discharge of sewage proper of 5 cubic feet per head per day, with provision for 0·01 of an inch of rainfall per hour in urban parts, and one-half that in the suburbs.

The author stated in 1881, in regard to the suggestions (then rife) to dispose of the sewage of London on land, that to enable the sewage then discharged into the Thames at Crossness and Barking to be diverted and utilised on land, an enormous expense would have to be incurred in the acquisition of the acreage required, as well as for the plant for pumping the sewage to a sufficient height to control this area. In his opinion, the crops produced on such sewage farms could not cover the

cost of the additional pumping to command them, and that the sanitary requirements of the case would probably be fulfilled by applying inexpensive chemicals to act as deodorants and precipitants, whilst avoiding an unnecessarily high standard of purity, and he gave evidence to that effect before the Royal Commission in 1884.

The Commissioners, in their second report, stated that the liquid portion of the sewage remaining after the precipitation of the solids may, "as a preliminary and temporary measure, be suffered to escape into the river, but it would require further purification, and this, according to the present state of knowledge, can only be done effectually by its application to land."

During the eleven years, however, that have elapsed since that report was issued, much has been learnt which points to the possibility of successfully treating the sewage of London at the present outfalls, without having recourse to land filtration, and the sewage of the Metropolis is now dealt with at the northern outfall at Barking, and at the southern outfall at Crossness, by precipitation on the lines suggested by the author.

The Metropolitan Board of Works carried out the recommendations of the Commissioners, Sir Joseph Bazalgette being the chief engineer. At first the precipitation system adopted was the intermittent one, the sewage being left quiescent for two

hours in tanks, but although this was the system advised by the Commissioners, the tanks have now been converted with great advantage by Mr. Binnie (the Chief Engineer of the London County Council) into continuous working by substituting weir walls at one end of the tanks.

It is estimated that the flow of sewage averages 40 gallons per head per day at the Barking outfall, and 50 gallons per head per day at the Crossness outfall. The volume, however, is subject to sudden variations when rain falls heavily. Of the whole sewage of the Metropolis, it has been ascertained that 96 per cent is discharged at the outfalls, and 4 per cent. by storm overflows.

The chemicals used at the metropolitan outfalls are about a quarter of a ton of lime in solution per million gallons, to which is added one grain per gallon of protosulphate of iron. In hot weather an acid solution of potassium permanganate is added to the effluent to oxidise the organic matter that has escaped.

The employment of copperas (protosulphate of iron) as a precipitant was first introduced by the author and Mr. Melliss, many years ago, at the precipitation works of the Coventry Corporation.

The Thames is now no longer polluted by the discharge into it of the untreated sewage of London, as was the case formerly. The polluted state of the river and of the foreshore in front of the outfall

MR. DIBDIN'S TABLE SHOWING THE REDUCTION OF OXIDISABLE ORGANI

(All Quantities are stat

Liquid used for Experiment.	Percentage Reduction of Dissolved Oxidisable										
	1	2	3	4	5	6	7	8	9	10	11	12.
Chemicals used in grains per gallon on the 23 Samples of Raw Sewage from the Metropolitan System.	Lime in solution .. .. .. 3·7	Lime in solution .. .. .. 5·0	Lime in solution .. .. .. 10·0	Lime in solution .. .. .. 15·0	Lime as Milk .. .. 15·0	Lime in solution .. .. .. 3·7 Iron sulphate .. .. 0·3	Lime in solution .. .. .. 3·7 Iron sulphate .. .. 1·0	Lime in solution .. .. .. 3·7 Iron sulphate .. .. 2·5	Lime in solution .. .. .. 3·7 Iron sulphate .. .. 5·0	Lime in solution .. .. .. 5·0 Iron sulphate .. .. 2·0	Lime in solution .. .. .. 5·0 Iron sulphate .. .. 4·0	Lime in solution .. .. .. 5·0 Iron sulphate .. .. 5·0
Average reduction	11	15	19	25	13	11	13	18	21	18	19	18
Cost per annum for chemicals	£ 13,505	18,250	36,500	54,750	54,750	15,695	20,805	31,755	50,005	32,850	47,450	54,750
Other sources ..	..	52	..	..	..	..	..	..	..	58	61	..
" " ..	..	..	10	..	..	..	..	..	..	..	..	56

	£	s.	d.	
Lime taken as costing	1	0	0	per ton.
Iron	2	0	0	"
Alumina	3	10	0	"

MATTER IN SOLUTION BY VARIOUS METHODS OF CHEMICAL PRECIPITATION.
(in Grains per Gallon.)

Organic Matter by Treatment of Liquid with

13	14	15	16	17	18	19	20	21	22	23	24	25
Lime in solution .. .. .. 5·0 Iron sulphate .. .. .. 8·0	Lime in solution .. .. .. 5·0 Iron sulphate .. .. .. 10·0	Lime in solution .. .. .. 10·0 Iron sulphate .. .. .. 10·0	Lime in solution .. .. 5·0 Alumina sulphate .. .. 5·0	Lime in solution .. .. 5·0 Iron sulphate .. .. .. 5·0 Animal charcoal .. .. 5·0	Lime in solution .. .. 5·0 Iron sulphate .. .. .. 1·0 Alumina sulphate .. .. 5·0	Lime in solution .. .. 7·0 Iron sulphate .. .. .. 1·5 Alumina sulphate .. .. 5·0	Lime in solution .. .. 10·0 Iron sulphate .. .. .. 2·0 Alumina sulphate .. .. 10·0	Lime in solution .. .. 14·0 Iron sulphate .. .. .. 3·0 Alumina sulphate .. .. 10·0	Lime in solution .. .. 15·0 Iron sulphate .. .. .. 3·0 Alumina sulphate .. .. 15·0	Lime .. .. 28·0 Iron sulphate .. .. .. 6·0 Alumina sulphate .. .. 20·0	Lime .. .. 56·0 Iron sulphate .. .. .. 12·0 Alumina sulphate .. .. 40·0	Lime .. .. 700·0 Iron sulphate .. .. .. 100·0 Alumina sulphate .. .. 500·0
25	25	30	18	22	20	22	24	21	26	24	31	52
76,650	91,250	109,500	82,125	237,250	89,425	100,375	178,850	200,750	268,275	401,500	803,000	9,672,500
61	69	..	..									
..	..	..	33									

Volume of sewage taken at 156,800,000 gallons per day.

works has been entirely changed, and is improving year by year as the original deposits of filth in the bed of the river get reduced or disappear. This improvement is evidenced by the presence of sea-gulls every winter at Westminster Bridge, and by the reappearance of fish that have long been strangers to the river. A seal was captured at Richmond in November last.

The actual cost in 1893 of disposing of the sewage of London, and of the precipitated sludge, is stated to be 2*l.* 7*s.* 3·42*d.* per million gallons, and 67,583¼ million gallons of crude sewage were received and treated. This cost included all working expenses, and allowance for capital outlay. The latter item must be regarded as exceptional, owing to some of the original outlay being for works which have now been disused or reconstructed. The cost of dealing with the sewage and sludge, without allowing for capital outlay, is estimated at about 30*s.* per million gallons. The sludge produced amounted to 2,021,000 tons in 1893, 2,052,000 tons in 1894 and 2,169,000 tons in 1895. It was sent to sea in ships which hold about 1000 tons each.

Mr. Dibdin (the chemist to the London County Council) experimented with sewage obtained from the metropolitan system, and his results are given in the table upon pp. 82 and 83. The further experiments made by Mr. Dibdin on the effluent sewage at Barking are given on page 166.

MASSACHUSETTS EXPERIMENTS.

The elaborate experiments carried out at Lawrence, and described in the reports of the Massachusetts Board, established some very useful practical results. Lime, copperas, alum and sulphate of iron were used as precipitants, either alone or in combination. It was found that there is a definite quantity of lime that will produce the best results with any given sewage, the quantity depending on what is necessary to neutralise the carbonic acid. A larger quantity would produce no better result. With the sewage experimented upon (see page 9), this quantity of lime was found to be 1800 pounds per 1,000,000 gallons of sewage. The best results that were obtained by chemical precipitation left as much as one-third of the nitrogenous organic matter of the sewage in the effluent.

The table on page 86 summarises the results of these experiments and indicates—

(1) That with a given quantity of sewage, a certain definite amount of lime gives as good or better results than either more or less.

MASSACHUSETTS EXPERIMENTS.

	Cost of Chemicals.*	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Residue.	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	Bacteria per Cubic Centimetre.	Yeast Cells per Cubic Centimetre.
	$									
Original sewage	..	0·40	43·0	18·0	25·0	1·25	0·40	4·86	25,840	20,700
Filtered through paper	..	..	34·8	11·2	23·6	1·25	0·26			
After settling one hour	..	0·30	38·8	13·6	25·2	1·25	0·28	4·82	10,920	16,700
Effluent with 1800 lbs. of lime per 1,000,000 gallons of sewage	0·30	0·08	45·6	10·2	35·4	1·25	0·19	4·83	1,911	1,650
Effluent with 1000 lbs. of copperas and 700 lbs. of lime	0·30	0·12	46·4	9·2	37·2	1·25	0·17	4·80	16,044	400
Effluent with 270 lbs. of ferric oxide	0·30	0·08	38·0	8·0	30·0	1·25	0·18	4·92	2,047	1,000
Effluent with 650 lbs. of alum	0·30	0·10	34·4	8·0	26·4	1·50	0·19	4·88	2,475	3,700
Effluent with 360 lbs. of ferric oxide	0·40	0·07	37·6	5·8	31·8	1·25	0·15	4·96	1,980	1,000
Effluent with 870 lbs. of alum	0·40	0·09	38·2	9·6	28·6	1·25	0·19	4·81	1,800	2,200

* Per inhabitant annually.

Soluble organic matter removed by chemicals at different costs.

	Per cent.
With lime costing 30 cents, per inhabitant annually	22
With copperas and lime costing 30 cents	29
With ferric sulphate costing 30 cents	32
With alumina sulphate eosting 30 cents	20
With ferric sulphate costing 40 cents	41
With alumina sulphate costing 40 cents	29
With lime costing 27 cents	20
With copperas and lime costing 20 cents	13
With copperas and lime costing 31 cents	39
With ferric sulphate costing 22 cents	17
With ferric sulphate costing 33 cents	48
With ferric sulphate costing 44 cents	46
With alumina sulphate costing 23 cents	10
With alumina sulphate costing 45 cents	47

(2) That in general, the more copperas, ferric sulphate or alumina sulphate used, the better the result.

(3) That ferric sulphate and alumina sulphate usually require no lime for completing precipitation.

(4) That with copperas a definite amount of lime must be used.

The practical deductions made by the experimenters were that the lime process has little to recommend it, owing to the large amount of lime water required, and the very close supervision that is necessary to accurately adjust the lime to the sewage.

Precipitation by copperas involves care in getting the right amount of lime mixed with the sewage before adding the copperas, but when this proportion is secured good results follow. The amount of iron left in the effluent is much greater than with ferric sulphate, owing to the greater solubility of ferrous hydroxide. Ferric sulphate and alum have advantages over the others, owing to success not being so dependent upon accurate adjustment of quantities, and as their addition in concentrated solution admits of being more accurately controlled.

Mr. Warington noticed that nitrification, like all fermenting processes, ceases in the presence of antiseptics, and this points to the necessity for excluding chemical refuse from sewers where the sewage has to be purified by nitrifying organisms. This was

also observed in the experiments at Lawrence on the intermittent filtration of sewage through a very coarse clean gravel filter. It was found that the addition of sulphuric acid resulted in a decreased nitrifying action. This experiment showed that sewage containing a large percentage of sulphuric acid may have the bulk of its organic matter removed by intermittent filtration, although if it is to to be constantly applied, the acid should be neutralised by some alkali. The effect of an acid sewage upon the discharge of bacteria from an intermittent filter was also noticed. The bacteria appeared to be few as long as there was much nitrification, but increased as the nitrification fell off. The nitrifying organisms were rendered comparatively inert by the acid, while the ordinary bacteria were less affected, and increased with the decrease of purification.

CHICAGO KINEBÜHLER TANKS.

At the Columbian Exhibition in 1893, provision had to be made for dealing with the sewage of the large population collected there, estimated at 150,000. The system adopted was similar to that carried out by Mr. Carl Kinebühler, at Dortmund in Germany some years ago, which attracted considerable attention. The main feature of this system consists in delivering the combined sewage and chemicals to the bottom of a precipitating tank, which is made of exceptionally great depth and of small area, so that the suspended matter has to rise through the body of fluid, and is arrested in the course of this vertical movement. The arrangement of the works at Chicago was as follows, so far as relates to the special features of this system. The sewage to be treated was received in a distributing tank 16 feet in diameter and 10 feet high, with a grating over the whole area 18 inches below the top. The sewage passed upwards through a vertical pipe 3 feet in diameter in the centre of this tank, and was distributed over the surface of the grating, leaving the larger solids on it. It then passed away through four outlet pipes 14 inches in

diameter, controlled so as to enable the sewage to be delivered into either of four precipitating tanks placed round the distributing tank, which was in the centre. Chemicals were added by suitable mixing arrangements, and the sewage thus treated passed to one or other of these special tanks, which were designed as follows. The main body of the tank was 32 feet in diameter and 32 feet deep, having a cylinder 6 feet in diameter, fixed vertically in the centre of it. This extends above the top of the tank and receives there the treated sewage, which passes down the cylinder to the bottom of it, and is conveyed by radiating carriers (suspended to the sides of this cylinder) and distributed inside the main tank at the depth of 32 feet. Below this the body of the tank contracts in the form of a cone for a further 22 feet (making the total depth 54 feet). At the bottom of this cone is fixed a pipe through which the deposited sludge can be forced by the head of sewage into sludge tanks, and thence to filter presses in the usual way.

After the treated sewage has passed down through the central cylinder, and up through the main body of the tank, the clear effluent is carried off by troughs 18 inches below the top of the tanks, leaving the available height of the circular part of the tank $30\frac{1}{2}$ feet. Allowing for waste space, the available capacity of the tanks may be taken as 237,000

gallons, of which about 54,000 gallons was afforded by the conical portion of the tank.

The precipitants employed were copperas, sulphate of alumina and lime, and the cost of the chemicals was about 8 dollars per million gallons.

Long vertical tanks, occupying a small area, offer advantages where space is limited, and other conditions are suitable to a system which consists of a continuous upward flow of treated sewage, with a continuous downward movement of the precipitate. A neutral plane appears to exist in these vertical tanks, and any organic matter which may rise past this plane comes under the further influence of the chemicals, and falls back through the upward current, forming a mass of flocculent matter at this neutral point, which arrests other matter that may be rising.

LIME PROCESS.

Lime being a cheaper precipitant than sulphate of alumina and other chemicals, it may seem that its use necessarily produces economic results. This is, however, not always the case, as any saving in the purchase of the cheaper precipitant may be more than counterbalanced in dealing with the large volume of sludge which it produces.

The effect of the addition of lime to sewage was carefully observed many years ago by leading chemists, and it was found by Dr. Letheby that the dissolved impurities were reduced from 70 to 67 grains per gallon, and the suspended matter from 19 to 1·7. Further experiments on London sewage showed that with 12 grains of lime per gallon, and with an average of many samples of sewage containing 15·0 grains per gallon of dissolved organic impurity, 4·20 only were removed, and of 94·0 grains per gallon of suspended and dissolved organic and mineral impurities, 54 grains only were removed.

In practice it is found that to enable perfect rest to be given to the combined precipitants and sewage, very large tank accommodation is involved, and to

obtain a clear effluent the process has to be worked on the intermittent, and not the continuous, system. In hot weather the lime process has to be used still more carefully, as putrefaction sets in rapidly, and both the effluent water and the sludge become offensive.

Numerous experiments have proved that in order to obtain satisfactory results the best lime only must be employed. Analyses of suitable and unsuitable qualities of lime have been made by Dr. Wallace, of Glasgow, and are as follows :—

Analyses of the Ingleton Lime used at the Bradford Corporation Sewage Works, *and of two other descriptions found to be unsuitable.*

——	Ingleton.	Shipley.	Knottingly.
Lime	94·78	65·94	60·76
Magnesia	·36	·99	·90
Oxide of iron	·14	·28	·70
Phosphoric acid	trace	·48	·06
Sulphuric acid	trace	3·46	1·63
Carbonic acid	3·05	6·40	17·54
Alumina	·75	3·75	1·75
Silica	·95	7·50	8·75
Water	..	10·36	7·63
	100·03	99·16	99·72

Note.—The Shipley and Knottingly lime had been kept for some time, and had absorbed some carbonic acid and water.

LIME PROCESS—BRADFORD.

The population is about 230,000, on an area of 10,776 acres, giving a population density of 22·3 per acre. There are about 7500 water-closets, 34,000 privies and 21,000 ashpits. The flow of sewage is about 9½ million gallons a day, or 41·3 gallons per head. The sewage is of a manufacturing character, containing much dye refuse.

Before the application of lime the solids are strained away from the sewage, yielding about 400 tons a year in a dry state, which are disposed of as garden manure at 6*d.* a load. After the removal of the solids, the sewage is passed through four culverts (to diminish its velocity), and it is then delivered into the precipitating tanks. There are 34 tanks, each 23 feet by 28 feet, having an average depth of 5 feet, the capacity of each being 18,000 gallons. The cost of the precipitation works alone may be taken at about 40,000*l.*

The combined sewage and lime are allowed to remain at rest in the tanks from half an hour to forty minutes. The supernatant water from the tanks passes through a series of 34 filter tanks, 12 feet by 23 feet, filled with 2 feet of coke. The

sludge gravitates from the precipitating tanks into a sludge collector, from which it is pumped on to open air drying beds specially constructed for that purpose. From these it is removed in a portable condition, a small portion being utilised by the farmers of the neighbourhood. The cost of the removal of the sludge is defrayed chiefly by the Corporation, as there is very little demand for it as manure.

The average cost of dealing with sewage and sludge has been 4000*l.* per annum.

Allowing 5 per cent. interest on the 40,000*l.* expended on the precipitating works and appliances, an addition of 2000*l.* would have to be made to the above sum of 4000*l.* to arrive at the total cost to the Corporation for the clarification of the sewage of Bradford.

About nine tons of lime are used per diem, or nearly one ton per 1,000,000 gallons. The lime requires to be thoroughly disintegrated and reduced to an almost impalpable powder, in order to ensure its being completely dissolved and mixed with the sewage, otherwise the quantity of lime that would be used to produce the same result would be much greater.

The necessity for employing only a suitable quality of lime has been already referred to in giving Dr. Wallace's analyses, and the following analysis was also made by him of Bradford sewage:—

ANALYSIS OF A SAMPLE OF SEWAGE TAKEN AT A TIME OF DAY WHEN IT WAS FOULEST.

	Grains per Gallon.
Ammonia, free or saline	9·3
(Equivalent to 133 parts per million.)	
Ammonia albuminoid	1·4
(Equivalent to 20 parts per million.)	

ANALYSIS OF EFFLUENTS.

	Grains per Gallon.
Ammonia, free or saline	·56
(Equivalent to 8 per million.)	
Ammonia, equal to nitrogen, combined in other forms	·28
(Equivalent to 4 parts per million.)	

WOLVERHAMPTON.

The area of this borough is 3440 acres, the rateable value is 267,372*l.*, and the population is about 83,000. The dry weather flow is about $2\frac{1}{2}$ million gallons per day, equal to 30 gallons per head of the population. This town is the home of the galvanised-iron trade.

Some twenty years ago a general scheme of sewerage and sewage disposal was carried out, and in the report of Mr. Berrington (the borough engineer), bearing date 1891, we find it stated that at first broad irrigation was unanimously adopted in preference to any other system, and a sewage farm was laid out, its situation enabling nearly all the sewage to be received by gravitation. For many years every effort was made to purify the sewage by broad irrigation, and then intermittent filtration was tried, but ultimately precipitation had to be resorted to.

From the first, Wolverhampton has had two difficulties to contend with, namely the peculiar nature of the sewage, due to manufacturers' waste-water, which, after treatment (as is required), still contains a great deal of iron and other matters:

and the smallness of the brook into which the effluent passes, the volume of the brook being considerably less than that of the effluent itself.

There are six precipitation tanks, each 150 feet by 50 feet, and from 5 to 6 feet deep.

The average amount of lime used is 20 grains per gallon. The quantity of wet sludge produced often amounts to 300 tons in twenty-four hours, that of pressed cake 50 tons, costing about 1*s.* 5*d.* per ton. The average time of pressing is forty-five minutes, and of filling, pressing and emptying is one hour.

The cost of tanks, engines and houses, boilers, pressing plant, &c., was 14,000*l.*

BURNLEY.

The area of the municipal borough is 1731 acres, which is divided into two drainage districts, the Gannow and Duckpits watersheds, having areas of 357 acres and 1374 acres respectively. The population was 82,000 in 1889, when the number of water-closets was 6586.

In the valleys of these districts sewage outfall works have been constructed, and the particulars here given are derived from the borough surveyor, Mr. F. S. Button. The precipitant is milk of lime, which is mixed with the sewage before its delivery into the settling tanks. In these a portion of the matters held in suspension are deposited, and the supernatant liquid flows over the tank sill and is filtered through land. The approximate quantity of lime used is 8 grains per gallon.

The Gannow outfall works (which are temporary) occupy a plot of land having an area of $1\frac{1}{4}$ acres, and the sewage from a population of about 12,000, or an average dry weather flow of 300,000 gallons per day, is delivered at these works. There are two settling tanks, 83 feet 6 inches long, 20 feet wide, and 4 feet 6 inches deep from bottom of tank to top

of overflow sill, with a capacity in each tank of 62,624 gallons. Each tank is divided by three partition walls into four compartments, in the first of which the bulk of the precipitated solids is intercepted by means of a solid wall. The two remaining partitions are formed of brickwork with apertures, which allow the sewage to pass through two filters of gas coke. The sewage remains quiescent in the tanks for about two hours.

The tanks are emptied as required, the sludge being pumped by hand into earth becks, where it is allowed to remain until it is sufficiently air-dried to allow of removal by the farmers in the neighbourhood.

The Duckpits outfall works occupy an area of about $5\frac{1}{4}$ acres, and receive the sewage from a population estimated at 66,000. The average flow is about 1,650,000 gallons per day, or 25 gallons per head per day.

The sewage on delivery at the works is first run through straining tanks, where the coarser particles are extracted, after which it receives milk of lime and passes along a salmon race to a series of eight tanks, 50 feet long by 39 feet 8 inches wide. The average depth of each tank from the overflow sill is 6 feet 3 inches, and the total capacity is 621,322 gallons. The flow through the tanks is continuous, and the effluent is filtered through about 60 acres of land.

About 350 tons of sludge are produced per week. This is dealt with in Johnson's filter presses, the sludge being first delivered into a tank holding 200 tons. This is provided with a skimmer for the removal of the top water from the surface of the sludge. It is found that when the tank has been filled with sludge from the settling tanks, and allowed to remain for twenty-four hours, about 12 inches in depth of water rises to the top of the sludge, and this is skimmed off and passed again through the settling tanks. The presses, which are three in number, contain forty chambers each, and turn out forty cakes of pressed sludge per press, each cake being 36 inches square and 1½ inches thick, the whole weighing 27 cwt. The time occupied in reducing the sludge to cake is a little over an hour per press, and from thirteen to fifteen pressings per day can be obtained from the three presses. The quantity of lime used in pressing the sludge varies from 150 lbs. to 200 lbs. per press, the variation depending on the character of the sludge.

The cost of pressing the sludge is about 2*s.* 6*d.* per ton of cake, or 6*d.* per ton of wet sludge. This cost is made up as follows: labour, 9½*d.*; lime, 9½*d.*; cloths, 6*d.*; coal, oil, repairs, &c., 5*d.*

At the present time about 400 tons of sludge are removed from the settling tanks weekly, and this quantity is reduced to 80 tons of cake by the three presses, at a cost of 10*l.*

The pressed cake is readily removed by farmers, some of whom come a distance of four miles, and at times carts have waited for the discharge of the cake from the presses.

The cake has been analysed by Dr. Campbell Brown, of Liverpool, and he estimates its theoretical value at 20*s*. per ton, which is about 25 per cent. higher than the theoretical value of farmyard manure.

BIRMINGHAM.

Mr. W. S. Till, the borough engineer, described the outfall works of the Birmingham, Tame and Rea District Drainage Board, in a paper read at the British Association in 1886, and Mr. J. Knight, his colleague, read a paper at the Mason's College Engineering Society in 1889, from which the following information is obtained.

The total area of the drainage district is 47,275 acres, the population in 1889 was estimated at 658,000, and the rateable value 2,500,000*l.* The total area of land available for works of sewage disposal is 1227 acres.

The nature of the land is very favourable to the purification of sewage, the natural surface of the ground being as a rule even and unbroken, and the level such as to admit of the irrigation of the whole by gravitation, with the exception of about 100 acres. The subsoil is gravel and sand, varying from 6 to 10 feet in thickness.

The sewage (amounting to 20 million gallons a day, dry weather flow) is brought to the land by a conduit 8 feet in diameter, having a fall of 2 feet per mile, and capable of discharging 38 million

gallons a day when running half full. From this conduit the sewage is distributed, firstly by open brick carriers, then by earth carriers.

The land is drained to a minimum depth of 4 feet 6 inches. The subsoil drainage consists of 3-inch and 4-inch agricultural drain pipes from 10 to 15 yards apart, delivering into main drains of from 9-inch to 18-inch, which discharge into the outfall channels. The total cost of the land and works to December 31, 1889, was 410,033*l*.

There are three large subsiding tanks, having a cubic capacity of 169,000 cubic feet, 154,000 cubic feet, and 116,000 cubic feet respectively. In these the grosser impurities are deposited.

There are four additional sets of tanks, having four tanks in each set, or sixteen altogether. Each of these is 150 feet long, 50 feet wide, and about 6 feet deep, their combined capacity being about 729,000 cubic feet.

The sewage is mixed with milk of lime, both to neutralise the acids (present to an unusual extent in Birmingham sewage) and also to assist precipitation. The limed sewage then passes gently through the large tanks, where the grosser impurities are precipitated, and from thence it is conveyed away by the main conduit, and disposed of by ordinary irrigation.

The sixteen small tanks, referred to as forming part of the complete precipitating process, are still used under certain conditions, and are valuable when

rainfall has increased the normal quantity of sewage. The sludge is raised into shoots, from which it flows into beds made on the land, and formed of turf or earth walls, about 10 yards square and 2 feet high. The sludge as it leaves the tanks contains at least 90 per cent. of water, but after lying on the ground from a fortnight to three weeks much of this water disappears, leaving the sludge of a consistency that admits of its being trenched into the land, on which crops are then planted.

146,468 cubic yards of mud were arrested in the tanks in the year 1888, or an average of 400 cubic yards per day. About 4000 tons of lime were used for precipitation purposes, or an average of 11 tons per day.

The Board farms all the land, none being sublet. Of the produce, milk is an important item, 133,787 gallons being sold in 1888, realising 4092*l*. 110 acres of land were devoted to rye-grass, 275 acres to cabbage and other vegetables, 174 acres to mangold, swedes and kohl rabi, 119 acres to cereals, and about 250 acres were pasture. The total amount realised in the year from the sale of stock and produce was 20,416*l*. During the same time stock was purchased to the amount of 7997*l*.

The total annual current expenditure on the sewage works and farm was 54,363*l*., and the income 20,533*l*, leaving a balance of 33,830*l*. Of this amount the interest and repayment of loans absorbed

18,387*l.*; rent, rates, taxes and management expenses, 5473*l.*; the balance of 9970*l.* representing the loss on the year's working of the farm. The great source of loss is the lime, wages, machinery expenses and other charges connected with intercepting and dealing with the mud from the tanks. The cost under this head was 10,987*l.*, and the corresponding income practically nil.

THE NATIVE GUANO PROCESS.

The A. B. C., or native-guano process, is now in operation at Kingston-on-Thames, under a subsidy from the Corporation. The chemicals employed are alum, clay, a little blood from slaughter-houses and carbon or charcoal waste. The blood, clay and charcoal act as absorbents, and cause the deposition of suspended and dissolved impurities which could not be removed by the salts of alumina or iron alone. Professor Dewar and the late Dr. Tidy stated, in a report made a few years ago, that this process "precipitates 60 per cent. of the organic matter in solution, and of the residue left in the effluent, at least two-thirds are non-albuminous, and therefore of a nature less liable to putrefactive and other changes."

The effluent is one of the best which has been produced from any precipitation process, and is permitted to be passed into the river Thames without filtration through land. The process is, however, more costly than where lime alone, or sulphate of alumina or iron, and lime, are employed. It must be stated, on the other hand, that the greater cost is said to be justified on the ground that the residual

sludge has a value which enables it to cover the extra cost. This point still offers a ground for contention. Dr. Wallace, of Glasgow, calculated the value of the sludge at 33*s.* per ton containing 12·60 per cent. of moisture.

The charcoal aids the deodorising properties of the sulphate of alumina, whilst the clay, in a state of fine subdivision, offers a large surface for the absorption of impurities which are carried down with the precipitate. The addition of the clay increases the bulk of the precipate, and when the resultant product realises the value claimed for it, the cost of obtaining the clay, and of manipulating the bulky product, would be justified. If, however, the value required to be realised to cover the cost of the process be not obtained, there are no sufficient reasons for incurring the expense of these ingredients, because a good effluent can be obtained by other methods at much less cost.

The author had to make an inspection of these works in 1890, and obtained the following information. The population contributing to the sewage was then upwards of 38,000, and the daily average flow was equivalent to 33½ gals. per head per day. The sewage is first treated by what is called the B.C. mixture, which is prepared by grinding together equal weights of clay and carbon with a small quantity of blood from slaughter-houses. The combined sewage and B.C. mixture then flow in an

inodorous state through an open brickwork channel in which it receives alum in solution (the A. of the process). The amount of carbon used is approximately 55 cwt. per day, clay 55 cwt., alum $17\frac{1}{2}$ cwt., and about 30 lbs. of blood. These proportions are varied with the time of year. The combined sewage and chemicals flow a distance of about 80 yards to eight precipitation tanks, 85 feet long, about 50 feet broad, with an average depth of 6 feet. Each tank holds 150,000 gallons, and is divided into two parts by a diaphragm wall which runs three-quarters of the length of the tank. The sewage is let in on one side of this wall, and the outlets for the sewage or effluent, and also the pipe to the sludge pump, are on the other side. Floating scum boards are placed about 10 yards from the inlet side, and arrest any floating substances. The sewage flows all round the diaphragm wall, by which the sludge has time to precipitate, but it can be passed directly through the diaphragm wall by opening doors that are fixed in arches at the bottom of the tank near the inlet. The doors are opened when the sludge is to be pumped out of the tanks, to allow of its passing from one side of the diaphragm wall to the other. Two sets of two tanks each are employed to deal with the sewage, working continuously. The effluent passes from the tanks through channels delivering into a culvert which discharges into the Thames at a distance of about 200 yards. There

is the usual floating draw-off pipe, which also discharges into this channel. The lowest stratum of supernatant water is again treated in the tank. The sludge is pressed into cakes (containing between 50 and 60 per cent. of moisture) 1½ inch thick, which are stacked for a time, and then passed through drying cylinders and converted into a granular powder containing about 30 per cent. of moisture. This is called Native Guano, the commercial value of which Professor Dewar and the late Dr. Tidy reported upon as follows :—

"As to the manurial value of the Native Guano, we are strongly of opinion that this must be judged rather by the practical results of the agriculturist than by presumed theoretical values based on analytical data, and on the price of ingredients not necessarily in the same physical or chemical condition. Recent research tends to show that very small changes brought about in soils may have very important indirect effects."

FRANKFORT-ON-MAIN.

Mr. W. H. Lindley (the engineer to the Magistracy of Frankfort), who carried out the precipitating works at this place, has given a description of them, from which the following information is obtained. The population in 1889 was 150,000. All the houses are completely drained. The average daily flow varies from $5\frac{1}{2}$ to $6\frac{1}{2}$ million gallons, and provision is made for dealing with a future dry weather flow of about $8\frac{1}{2}$ million gallons, and a wet weather flow of double that. The site for the outfall works was selected on the bank of the river Main, at a point which enables the effluent to be used for irrigation purposes in the future. Storm overflows are provided which only come into use when the rainfall doubles the average daily flow. The sewage on arriving at the outfall enters a depositing chamber in which its velocity is retarded to $\frac{1}{10}$ of that in the sewer. Here the heavier suspended matters are deposited, and the sewage passes under scum boards (which arrest the floating substances) to a chamber in which the chemicals are added. Thence it flows along a channel to the precipitating tanks, in which the velocity of flow is reduced to $\frac{1}{100}$ of the velocity

it had in the sewer. The tanks are calculated on the basis of the sewage taking six hours to pass through. They are 80 metres long, 2 metres deep at the inlet end, and 3 metres deep at the outlet end. The total volume contained in each tank is 1100 cubic metres. The velocity at the inlet is five millimetres per second, and at the outlet end it is three millimetres per second, or an average rate of flow through the tanks of four millimetres per second. There are at present four tanks, which as a rule are all at work except when the sludge is being removed once in eight days, and this occupies about five hours. The precipitants employed are lime and sulphate of alumina containing 14 per cent. of pure alumina. The average quantity used is one ton of alumina to 6000 cubic metres of sewage, and the proportion of lime to alumina is as 1 to 4. The quantity of chemicals used is varied according to the quality and volume of the sewage, which are determined by a systematic inspection of samples taken.

Five sets of experiments have been made to determine the relative values of the lime and alumina. Three were made with lime and sulphate of alumina, two with lime alone, and one without any chemicals. Analyses made by Dr. Lepsius showed that the addition of the alumina produced a most beneficial action, as it removed all of the suspended impurities and 40 per cent. of the organic matters in solution. Dr. Libberty made some bacteriological

tests, and showed that where the average number of germs capable of development in raw sewage was three million per cubic centimetre, the number was reduced to 380,000, and 17,500, germs per cubic centimetre respectively by the two systems of chemical precipitation. Besides the greater purification effected by the use of sulphate of alumina, the bulk of the sludge was reduced to from one-third to one-fourth of that produced by the lime treatment alone. The annual cost of treatment in 1889 was 7500*l.*, or 1*s.* per head of the population.

RICHMOND.

The Richmond Main Sewerage Board dealt at first with the sewage of Richmond, Mortlake and Barnes, but the parishes of Kew and Petersham, and a portion of the parish of Mortlake called North Sheen are now taken in. The area is now 4983 acres, with a population of 43,924, and an assessable value of 343,729*l*. The outfall works were designed and carried out by Mr. J. C. Melliss, and are now under the charge of Mr. William Fairley.

The site of the works is 12 feet above Ordnance datum, or 2 feet 6 inches below ordinary high-water spring tides. The level of high water at this part of the Thames is, at ordinary spring tides, 14 feet 6 inches above Ordnance datum.

The sewers have been calculated to receive only a limited quantity of rain and subsoil waters in addition to the sewage proper.

The sewage is pumped from the low-level sewers to a sufficient height to gravitate to the river, three sets of pumps raising 7728 gallons per minute, or 11,128,320 gallons in twenty-four hours.

A certain amount of sewage can be stored in the pump well, and in the intercepting sewers of the

Board, without materially affecting any of the contributary districts. By means of this storage it is possible during dry fine weather to stop for a few hours, and make any necessary repairs or alterations to the pumps or engines.

The sewage, on entering the works, passes through a large screen situated in a straining well between 30 and 40 feet underground, where the rougher material is taken out, the screen being cleaned once a day. After leaving the straining well, the sewage is run into the pump well, and on entering, it receives a small dose of diluted carbolic acid and iron salts. After being pumped up to the higher level, it receives the addition of milk of lime, the proportion varying very much according to the season of the year, and the condition of the sewage, but approximately the average quantity added to the sewage does not exceed 4 or 5 grains per gallon.

The lime used is the best Buxton lime, delivered at Kew Bridge Station in truck loads, at 17*s.* 6*d.* per ton.

The chemicals next added at present consist of block alum (that used by paper-makers) and carbferalum, a compound of sulphate of alumina, carbon and iron. The average quantity varies, but 7 grains per gallon may be taken as a fair average for normal sewage. The price paid at present for the above mixture, but exclusive of lime, is

2*l.* 8*s.* 6*d.* per ton. The proportions vary according to the condition of the sewage.

The sewage then passes to the precipitation tanks, of which there are eleven, having a total capacity of 1,210,000 gallons. After being allowed to settle, the effluent water is run through the filter beds, and is finally discharged into the river.

The area of filters provided is $1\frac{1}{2}$ acres. Of this, 1 acre is situated at a high level, and is divided into $\frac{1}{4}$-acre plots. The remaining $\frac{1}{2}$ acre is situated at a level 2 feet lower than the other beds, and is divided into four plots $\frac{1}{8}$ acre each. The thickness of the filtering material varies from 15 inches to 2 feet 6 inches. The top is covered with a layer of loam, sown down with a selected mixture of grasses.

Up to the present moment, although these filter beds have been in almost daily use, no repairs or renovation of the filtering media, or surface soil, has been required. Practically the only expense incurred has been that of cutting the crop of grass nine times in the year, and removing any coarse grasses or weeds.

For the year 1893–94, the total cost of chemicals, including lime, was 25*s.* per million gallons of sewage treated, or three-tenths of a penny per thousand gallons. The year in question was exceptional, owing to the long drought, during which on many occasions larger quantities than usual of chemicals

had to be employed, the sewage being very foul and difficult to treat.

During the past three years the effluent has been under the inspection of the Thames Conservancy.

The following is an analysis made by Mr. Carter Bell, of Salford :—

	Sewage.	Effluent, Unfiltered.
Free ammonia	8·00	4·20
Albuminoid ditto	·56	·20

Percentage of purification—64.

The sludge having been deprived of some of its water by subsidence in the sludge chamber, is lifted by pumps into iron receivers (placed in the press-house), which contain a charge for one press. In these a small quantity of lime is added so as to facilitate the operation of pressing.

The quantity used and added to the wet sludge before it is forced into the presses is about 90 lbs. per press, or about 4 per cent. of the wet sludge.

The water pressed out of the sludge passes to the pump chamber, and mixes with the sewage to be treated over again. The solid sludge-cakes measure 3 feet square by 1½ inch in thickness.

The total amount of wet sludge produced in one year is approximately 30,000 tons, equal to 41·1 tons per million gallons of sewage treated, or 1·8 tons per 1000 persons daily. This latter figure is above

the average, but is due to the fact that the population during a portion of the year exceeded that taken as resident in the district.

In the year 1893–94, the average cost per ton of pressed sludge turned out between the hours of 6 A.M. and 5 P.M., was as follows :—

	£	s.	d.
Labour	0	1	0·4
Lime	0	0	9·2
Cloths	0	0	4·0
Coal, oil and stores	0	0	3·0
	£0	2	4·6

Although the cost for lime, cloths, &c., is the same for both night and day work, yet, owing to the smaller quantity that can be turned out by the night workmen, the extra expense for labour, &c., raises the cost to 2*s.* 10*d.* per ton.

All the sludge produced is removed by a contractor in covered sailing barges, each barge taking an average of about 80 tons, and the price paid is 2*s.* per ton, equal to about 1*s.* 6*d.* per cubic yard. The cakes are utilised for agricultural purposes in Essex and Kent.

GLASGOW.

The pollution of the river Clyde by the sewage of Glasgow has for many years engaged the attention of the Corporation, and a scheme was once proposed by the late Mr. Bateman and Sir Joseph Bazalgette to construct an outfall sewer to convey the sewage away seaward. The corporation, however, have recently carried out works for the purification of the sewage by chemical treatment. The construction of the Glasgow Central Railway appears to have facilitated the execution of this scheme, inasmuch as nearly a quarter of a million sterling was expended by the company in intercepting old sewers, and in reconstructing main sewers, immediately north of the railway, which sewers served a useful purpose as they enabled the drainage from 2600 acres, with a population of 156,000, to be carried to outfall works.

A main outfall sewer 7 feet 6 inches in diameter has been constructed, the discharge from which was 2,493,000,000 gallons for the year 1894 to 1895, when the works first came into operation. The sewage has to be pumped at the outfall and this

involved an expenditure of 1700*l.* for the year or 13*s.* 8*d.* per million gallons. The composition of the sewage varies at different times of the day, as is shown by the following table:—

—	Grains per Gallon.		
	1 p.m.	6 p.m.	12 Midnight.
Matters in Solution.			
Oxygen absorbed (in one hour)	11·20	2·52	·91
Ammonia, albumenoid	·469	·569	·232
Matters in Suspension.			
Organic matter	28·7	14·0	7·0
Mineral matter	16·1	18·2	5·6
Total solid matter.. ..	44·8	32·2	12·6
Colour (Loch Katrine = 10) ..	500	40	25

When the sewage reaches the outfall works it first passes through three rotary screens 4 feet wide, constructed of $\frac{3}{4}$-inch bars riveted $\frac{5}{8}$ inches apart on cross-bars (like link belting), with lifting plates 6 inches deep, at intervals of 4 feet. These screens are set at an angle of 45°, and travel at the rate of 14 revolutions per minute in the channel in which the sewage is flowing. The greater part of the rubbish remains on the bars and lifting plates, and

this is tipped into a square wrought-iron hopper which is emptied daily. The sewage passes from the bottom of the rotary screens into catch-pits which adjoin. These are 47 feet 10 inches long by 20 feet broad and 28 feet 6 inches deep. Here the solid matter is deposited, and is raised by elevators into railway wagons. The sewage is then lifted 25 feet, by centrifugal pumps, into a 3 feet 9 inch main which conveys it to the precipitation works, where it is treated with sulphate of alumina and lime.

There are 24 precipitation tanks, and 24 aeration beds. The beds and tanks are arranged in rows, the aeration beds being on either side. The precipitation tanks are 50 feet long, 40 feet wide, and 6 feet deep, with a capacity for 81,000 gallons each. The aeration beds are 43 feet by 40 feet, with a fall of 3 in 100, with occasional very shallow steps. The effluent channel in the centre is 17 feet 6 inches wide.

The tanks were designed to work either on the intermittent or on the continuous system, but the former has been adopted. Each tank can be filled in seven minutes, and the precipitation is completed in 45 minutes. The sewage is first treated with milk of lime and then with sulphate of alumina. The amount of chemicals used varies with the colour of the sewage. The following table shows the normal quantities employed :—

Colour of Raw Sewage.	Alumina. Grains per Gallon.	Unslaked Lime. Grains per Gallon.
Grey	5	$2\frac{1}{2}$
Dark grey	$7\frac{1}{2}$	$3\frac{3}{4}$
Very dark grey	10	5
Light brown	15	$7\frac{1}{2}$
Blue	20	10
Brown	30	15
Dark brown	40	20

Frequently with afternoon sewage 171 lbs. is used per 35,000 gallons = 34·5 grains per gallon.

The effluent is drawn off from the surface of the tanks by floating arms in the usual way, and flows over aerating channels made of blue bricks, to 20 coke filters, each of which is 40 feet by 10 feet by $3\frac{1}{2}$ feet. The filtered effluent then passes in a 3-foot open channel to 40 sand filters, the size of each being 40 feet by 38 feet by 2 feet 3 inches, formed of about 18 inches of Arran sand, and the same thickness of whin metal. The following figures give the amount of the impurity that is removed, both by coke filtration, and by coke and sand filtration.

	Filtration.	
	Coke only.	Coke and Sand.
Organic matter	72 per cent.	81 per cent.
Albuminoid ammonia ..	34 ,,	53 ,,
Colour	80 ,,	88 ,,

The proportions of the chemicals employed are varied to meet the great changes that occur in the composition of the sewage, which is due to the discharge from dye-works and tanneries. On Saturdays, Sundays, and during holidays, the sewage is practically of a domestic character, when the cost of chemicals does not exceed from 10*s.* to 12*s.* per million gallons; but there are many working days when the cost reaches as high as 54*s.* per million gallons. The average is from 25*s.* to 30*s.* per million gallons.

The analyses on page 124, made by Mr. R. R. Tatlock (the city analyst), represent two typical cases, one for week-day sewage, and the other for Sunday sewage; the effluent being filtered through sand as well as coke.

The sludge passes by gravitation into a collecting tank 80 feet by 46 feet, and about 22 feet below the floor level. A cylinder (containing 1800 gallons) is placed close to this tank, and the sludge gravitating into it, is forced (by the exhaust air from the sludge presses) a height of 27 feet to the sludge-mixers. A solution of hot lime is here added to the sludge to facilitate pressing, the quantity being 46 pounds of lime to the 900 gallons of sludge that the mixer holds. The mixed sludge and lime are then forced (at a pressure of 100 pounds to the square inch) into the filter presses which are placed on a floor above.

There are seven of these presses, and they deal with 60 tons of wet sludge per day, each press making 41 cakes at a time, occupying about three hours.

ANALYSES IN GRAINS PER GALLON.

	Weekday.		Sunday.	
	Raw.	Effluent.	Raw.	Effluent.
Matters in Solution.	grains per gal.	grains per gal.	grains per gal.	grains per gal.
Oxygen absorbed ..	3·42	·72	·68	·14
Ammonia, albuminoid	·427	·238	·448	·105
,, free	1·435	1·715	1·575	·595
,, total	1·862	1·953	2·023	·700
Organic matter	12·04	5·60	7·00	1·88
Mineral ,, ...	55·16	40·04	24·36	37·32
Total solid matter ..	67·20	45·64	31·36	39·20
Matters in Suspension.				
Organic matter	17·5	..	2·1	
Mineral ,, ...	11·9	..	4·2	
Total solid matter ..	29·4	..	6·3	
Alkalinity (as carbonate of lime)	26·60	22·96	18·76	18·20
Colour (Loch Katrine = 10)	240	24	44	8

The following are analyses of the pressed sludge, one being that of the cake as it came from the press, and the other that of the cake dried in the laboratory :—

CHEMICAL REPORT ON SAMPLES OF PRESSED CAKE.

	Wet. Per cent.	Dry. Per cent.
1. Organic matter	13·88	45·24
2. Mineral matter	16·80	54·76
Water	69·32	—
	100·00	100·00
1. Containing nitrogen ..	·53	1·73
Equal to ammonia	·64	2·10
2. Containing phosphoric acid	·38	1·23
Equal to tribasic phosphate of lime	·83	2·70

The works cost 105,000*l.* (38,000*l.*, being for the acquisition of the site). The area of the site is capable of dealing with double the present quantity of sewage. The table on page 126, by Mr. Melvin (the works manager), shows the cost of treatment for the year 1894–5.

The works were designed and carried out by Mr. G. V. Alsing, the borough engineer, who brought to bear on their design the great experience he had gained in connection with the sewage disposal works at Bradford.

Cost of Treatment of Glasgow Sewage for One Year, 1894–5.

—	May to July.	August to October.	November to January.	February to April.	Totals.
Number of gallons dealt with	458,990,000	537,785,000	697,679,000	784,861,000	2,493,315,000
Cost of chemicals per million gallons	22*s.* 4*d.*	26*s.* 1*d.*	27*s.* $1\frac{3}{10}$*d.*	30*s.* $8\frac{7}{10}$*d.*	
	tons cwt.	tons cwt. qrs.	tons cwt.	tons cwt.	tons cwt. qrs.
Crude sludge..	28,971 16	28,069 3 2	36,025 5	34,521 13	127,587 17 2
Pressed sludge cake	2,593 15	2,417 10 0	2,853 15	2,866 16	10,731 16 0
Cost of pressed cake per ton	3*s.* 1·4*d.*	3*s.* 2·5*d.*	2*s.* 9·05*d.*	2*s.* 9·1*d.*	2*s.* $10\frac{1}{2}$*d.*
Cost per Million Gallons.	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*
Pumping	1 0 $3\frac{3}{10}$	0 15 $0\frac{3}{10}$	12 1	10 $4\frac{9}{10}$	13 $8\frac{2}{10}$
Precipitation, including chemicals, labour, &c.	1 12 $9\frac{2}{10}$	1 14 $2\frac{6}{10}$	1 14 $3\frac{5}{10}$	1 15 $6\frac{5}{10}$	1 14 $4\frac{6}{10}$
Filtration, incl. coke, sand, &c.	0 4 $4\frac{6}{10}$	0 7 11	7 $8\frac{4}{10}$	7 $10\frac{1}{10}$	7 $2\frac{3}{10}$
Pressing sludge	0 16 $9\frac{4}{10}$	0 14 $1\frac{3}{10}$	11 $3\frac{2}{10}$	10 1	12 $8\frac{3}{10}$
Total cost	3 14 $2\frac{5}{10}$	3 11 $3\frac{2}{10}$	3 5 $4\frac{1}{10}$	3 3 $10\frac{5}{10}$	3 7 $11\frac{4}{10}$

THE AMINES PROCESS.

This process employs herring brine with milk of lime as the precipitants. An experiment was made with it at Salford, from July 13 to 27 in 1891, with the six precipitating tanks at the outfall works there, which had an aggregate capacity of $2\frac{1}{2}$ million gallons. The following information is based on a semi-official description of the experiment.

The sewage treated in the fortnight was 84,623,300 gallons. The quicklime used was 120 tons 13 cwt. 3 qrs. = $22\frac{1}{2}$ grains per gallon. The herring brine used was 21 tons 10 cwt. 3 qrs. = 4 grains per gallon, the cost of these materials being 1*l.* 15*s.* per million gallons. The wet sludge produced was 2211 tons 3 cwt., or about 26 tons per 1,000,000 gallons. Dried at 212° F. (the moisture being about 92 per cent.), this would give dried sludge about 177 tons, which as pressed cake (with 50 per cent. of moisture) is equivalent to 354 tons, or about $4\frac{1}{4}$ tons per 1,000,000 gallons.

The effluent going continuously over the sill of the overflow tank was stated to be uniformly clear, bright and odourless; a layer 1 inch in depth in a

white porcelain vessel was colourless; a white tile immersed in the overflow tank could be distinctly seen at a depth of from 3 feet 6 inches to 4 feet. At the close of the trial an uncovered galvanised iron tank holding 100 gallons was, by direction of the referee-chemist to the Corporation, filled with effluent from the overflow tank, and was kept exposed to the influence of the atmosphere, and frequently to the rays of the sun, for nearly three months, at the end of which time it was, according to the works manager, as sweet and clear as when it was first put into the tank.

Dr. Klein reported that, while the sewage samples submitted to him from the experiments at Salford yielded on plate cultivation above 10,000,000 colonies of bacteria per cubic centimetre, the effluent yielded only 10 colonies (two of which were moulds accidentally acquired from the air). The Irwell water he found to yield on an average 80,000 to 100,000 colonies per cubic centimetre.

PRECIPITATION OF SEWAGE BY ELECTRICITY.

Many years ago the author considered the possibility of precipitating the organic matters in sewage by electricity, but concluded that, although theoretically quite feasible, it would be commercially less advantageous to towns than by other methods. He, however, wishes to give fair prominence to the efforts in this direction which have been made by some who have taken a less pessimist view.

Mr. Webster's system of precipitating sewage by electrolysis was tried on a practical scale, in 1888–9, at the South Metropolitan outfall at Crossness, where an experimental plant was put up to treat 500,000 gallons of London sewage a day. This was raised into a tank from which it flowed through a shoot or channel 400 feet long, in which were placed the electrodes in groups of 15 plates each, parallel to the sides of the channel, and about an inch apart. There were 22 sets of 15 wrought-iron plates (pig iron would do) each in parallel, and six sets each in series. The difference of potential was 2½ volts. The sewage took about 10 minutes to traverse this channel, but it was exposed to the electrolytic action in the channel a longer or shorter time according

to the degree of pollution. It was estimated that, on the average, it required ·25 ampère hours of current for each gallon treated, the current density being one ampère per 11 square feet of electrode. The sewage, after being decomposed by this treatment, passed into a settling tank, where it remained at rest for an hour or two, the hydrogen gradually disengaging itself, and the coagulated particles sinking as sludge.

The chemical reactions have not been clearly ascertained, but the nascent chlorine and the oxygen were carried to the positive electrodes, and there they rapidly oxidised the organic matter. The iron was also dissolved as a hypochlorite, and, combining with suspended matter, coagulated it in flocculent particles. These were buoyed up by the hydrogen bubbles, and rising to the top as froth, left a clear liquid beneath. It was found by analysis that the amount of iron dissolved was equal to two grains per gallon treated. No positive estimate of cost was made; the working expenses were for coal, iron and labour, and it was alleged that these would amount to 13*s.* per million gallons of London sewage, if treated on a large scale. Interest and depreciation of plant have, however, to be added to this, together with the cost of dealing with the sludge.

This is in reality a chemical process in which the chemicals are to a great extent manufactured from

the sewage itself, and are used in the nascent state, when it is well known they are most powerful. The average of 20 analyses of sewage before and after treatment showed that of raw sewage, very turbid and opalescent, containing 33·35 parts of suspended matter in 100,000, the effluent was clear, containing 1·56 parts per 100,000, mainly oxide of iron.

Sir Henry Roscoe investigated the process and stated that the effluent from it showed no signs of putrefaction, but on the contrary a tendency to oxidise, and that by the process the soluble organic matter was reduced to a condition favourable to the further precipitation by natural agencies. He also found that in experiments carried out with Paris sewage, in which the organisms were five million per cubic centimetre, there were only six hundred in the effluent.

HERMITE PROCESS.

Another method of sewage purification which employs electricity is the "Hermite," and it is based upon producing an antiseptic or deodorising liquid by passing an electric current through sea water, or, if sea water is not available, through a solution of magnesium and sodium chlorides, and applying the resultant disinfecting liquid to sterilise the sewage in the town itself, instead of, as in other systems, treating it at an outfall. The following data are derived from the statements of those who are interested in the process, especially Messrs. Paterson and Cooper, the engineers.

The electric current has an electromotive force of 6 to 7 volts, and a variable quantity which may reach 1200 ampères. This produces the decomposition of the chloride of magnesium contained in the sea water, the products being magnesia, and an oxygenated compound of chlorine. The magnesia is carried to the negative pole. The oxygenated compound of chlorine, which is produced at the positive pole, is dissolved in the water, to which it gives its deodorising and antiseptic properties.

Sea water can be electrolysed to various strengths

of chlorine, corresponding to the smaller or greater quantities of chlorine set at liberty by the decomposition of the chloride of magnesium.

The apparatus by means of which the sea water is electrolysed consists of a galvanised-iron tank in which are platinum and zinc electrodes. The platinum electrodes are constructed of platinum-wire gauze; the zinc electrodes are discs of pure zinc, a series of which are threaded upon two spindles, with room between them for the platinum electrodes to be inserted. The zinc electrodes being attached to a spindle, revolve, and have scrapers acting on them for the purpose of removing the deposit of magnesium oxide which coats their surface during the electrolysis. The normal size of these electrolysers is such, that a current of 1000 or 1200 ampères may be employed, and the electromotive force may be taken approximately at 6 volts. On filling the tank with sea water, and passing the current through the electrolyser, the electrolysis of the sea water is brought about with the result that in the place of magnesium chloride, a hypochlorite of magnesia, and a precipitation of magnesium oxide, are obtained. This hypochlorite of magnesia is a complex salt, inasmuch as it holds in suspension a certain amount of nascent oxygen, resulting from the decomposition of the water which goes on at the same time, and it is this nascent oxygen, held in suspension by the magnesium hypochlorite, which is considered to

be the antiseptic and deodorising agent. It is stated by those interested in this process that it is perfectly easy to electrolyse sea water, and not to get good results, or only to get them partially, unless two or three points connected with this process are borne in mind. One is, that the longer the electrolysis goes on, the larger is the amount of hypochlorite formed, and the greater the concentration of the resulting antiseptic; and further, that the longer the electrolysis goes on, the larger is the amount of time necessary to raise the solution a step higher in antiseptic power.

In all the experiments that have been made, 1 gramme per litre has been the limit of strength which it has been found necessary to work up to, even for dealing with sewage requiring a very strong antiseptic; and with such a machine as has been referred to, 1000 litres can be raised to a strength of 1 gramme per litre in one hour with the consumption of 1000 ampères at 6 volts.

The advocates of this process claim that the cost of producing one gramme per head in 24 hours, which is stated to be sufficient to deodorise and partially disinfect the sewers, would represent 1½*d.* per head per annum, although it may reach 1*s.* per head.

The Hermite system has been considered as a plan for conveying this antiseptic into the houses for flushing the closets with it, but it admits of being

used for treating the sewage in the sewers as high up as it is found economical or advantageous to go.

The great advantage insisted on by those who have interested themselves in this system is that by its adoption the fluid refuse passing away from a house is either deodorised or disinfected before leaving the dwelling, or is so treated in the public sewers shortly afterwards, by which means disease germs are destroyed instead of developing during the time the sewage is flowing.

The following opinion of Dr. Klein may be quoted:—

"Ordinary raw sewage of London, Manchester, and other towns that I have examined, contains between 3,000,000 and 10,000,000 of bacteria per c.c.; this "treated" sewage effluent of Worthing contains only 800 to 1000 microbes per 1 c.c. It follows that there has been effected by the mixture of the Hermite solution a remarkable reduction in the number of living microbes. After treatment of the original cultures with the same bulk of Hermite solution for 20 minutes, similar plates were made, and the number of colonies coming up in these plates was compared with those of the previous control plates. It was found that by the Hermite solution the number of living microbes was reduced something like over 100 times."

The system has been recently carried into practical operation in Ipswich, where the Hermite

solution is run into the main sewer near its commencement, and the treated sewage is discharged into the river Orwell. Mr. J. Napier, the Borough and County Analyst, read a paper on the chemistry of the process before the British Association this year, and his opinion appears to be favourable.

THE INTERNATIONAL COMPANY'S PROCESS

The process of purifying sewage by the International Company's system deserves mention. The sewage solids are first precipitated by a material called Ferrozone, which is rich in ferrous iron, alum, magnesia, and magnetic oxide of iron, in a very spongy and absorptive condition.

The following is Sir Henry Roscoe's analysis of this material :—

ANALYSIS OF "MAGNETIC FERROUS CARBON" (FERROZONE).

Soluble constituents :—	
Ferrous sulphate	26·64
Aluminium sulphate	2·19
Calcium sulphate	3·30
Magnesium sulphate	5·17
Combined water	8·20
Moisture	24·14
Insoluble constituents :—	
Silica	11·35
Magnetic oxide of iron	19·01
	100·00

The second part of the process is the purification of the effluent by a material called Polarite, and Sir Henry Roscoe, in 1888, describes Polarite in these words :—

"The porous nature of the oxide which is used in the filter, its complete insolubility and its freedom from rusting, constitute in my opinion its claim to be considered a valuable filtering material. A sample of this filtering material, taken at Acton, gives the following results on analysis :—

ANALYSIS OF POLARITE.

Magnetic oxide of iron	53·85
Silica	25·50
Lime	2·01
Alumina	5·68
Magnesia	7·55
Carbonaceous matters and moisture ..	5·41
	100·00"

He also gave the following analyses :—

ANALYSIS OF UNFILTERED EFFLUENTS.

	Parts per 100,000.	Grains per Gallon.
Chlorine	6·2	4·34
Free ammonia	1·1	0·77
Albuminoid ammonia	0·071	0·050
Oxygen absorbed from permanganate in 4 hours	0·652	0·459

ANALYSIS OF FILTERED EFFLUENTS.

	Parts per 100,000.	Grains per Gallon.
Chlorine	6·4	4·48
Free ammonia	0·406	0·284
Albuminoid ammonia	0·025	0·018
Oxygen absorbed from permanganate in 4 hours	0·325	0·228

In order to assist the action of a filter in which Polarite is used, the patentees have recently arranged a filter which is aerated by air brought from the surface. The construction of the filter is as follows. The upper layer consists of about 10 inches of clean sharp sand, on the surface of which the sewage effluent is distributed. Beneath this is a layer of 1 inch of grit, of a size to pass through a mesh of four holes to the square inch. Then comes a layer of 2 inches of pea gravel, and beneath that is 4 inches of stone or gravel, the size of which is 1 inch or $1\frac{1}{2}$ inches. This forms the aerating layer into which are brought 3-inch vertical pipes placed about 6 feet apart. These pipes come down on one side (with a bend into the layer) from an inlet above the surface of the filter. On the other side they are carried up to a cowl outlet above the surface of the filter. This arrangement is relied on to aerate the impure water which trickles over the surfaces of the stones in this layer. After this aeration, the fluid filters downwards through 6 inches of Polarite, under which is a layer of 1 inch of grit passing through a mesh of eight holes to a square inch. Then it filters through 1 inch of pea gravel, 2 inches of bean gravel, and, at the bottom of all, 4 inches of broken stone, in which 3-inch agricultural drains are laid, 3 feet apart.

Experiments were made in 1893 at Lawrence, Massachusetts, with a filter $\frac{1}{20000}$ of an acre area,

having a layer of Polarite 7 inches deep, the top being 6 inches below the surface, and beneath the Polarite was 5 feet 3 inches of sand ·48 of a millimetre in size. The experiment was made to remove colour from sewage containing dye stuffs. The rate of filtration was 160,000 gallons per acre daily for six days in the week for eight months, when the rate was doubled. The quality of the effluent was uniformly good for three weeks, when clogging occurred at the surface of the Polarite. The filter was allowed to rest for between two and three weeks, when sewage at the rate of 160,000 gallons a day was applied. The effluent was well purified, but clogging gradually reappeared. Then, for about five weeks, aniline dye was put in the sewage, in the proportion of ·33 parts per 100,000. The effluent was slightly coloured after a few days, and became quite marked after 38 days. The dye was then discontinued. During these periods another filter of the same construction, but without the Polarite, was similarly treated, and each was found to effect equally uniform purification attended with high nitrification.

Dundrum Asylum.

Mr. Kaye Parry (with Mr. Walter Adeney and Mr. James Carson) experimented on the purification of sewage at the Dundrum Asylum (in Ireland), containing about 250 people, the dry-weather flow

being 6000 gallons. This sewage passed through a straining chamber, and then to the bottom of the first of three tanks, 7 feet square, and 16 feet deep, each containing 5000 gallons. In rising to the surface from the floor of the tank the finer particles, constituting much of the suspended matter, are arrested mechanically. The clarified sewage is then carried to a second and similar tank, passing *en route* through a mixing race, in which it receives a dose of manganate of soda, from two to five grains per gallon (or manganate with sulphate of alumina). This oxidises part of the organic matter, which falls to the bottom of this tank. The liquid then passes to a third tank, where nitre is added in the proportion of two or three grains per gallon, the purification being completed by the action of micro-organisms. These tanks are filled and emptied every 24 hours, the final effluent being stated to be clear and non-putrefactive. The sludge is drawn from the first tank, strained through canvas sacks, and spread over the floor of a drying shed; a little of the manganese recovered from the second tank is added, and the two are worked up together and dried into a manure.

Halifax has given this process a trial; and interest attaches to it, inasmuch as the system is based on utilising the functions of bacteria, which play so important a part in sewage purification.

SHONE'S EJECTOR.

When sewage has to be raised at places where the establishment of a steam pumping station would be undesirable, or would raise opposition, the power necessary to lift the sewage at such points can be developed at any convenient spot at a distance (by one of the several available systems) transmitted to these points, and applied to suitable lifting machinery placed in chambers beneath the surface of the ground. One appliance that is much employed under these circumstances is Shone's Ejector, which is an automatic arrangement by which compressed air, produced at some distant air-compressing station, is applied to the surface of sewage collected in a closed receiver. The air pressure forces the sewage out of the receiver to the sewer at a higher level. The operation is automatically controlled by a float, which rises, as the chamber fills with the sewage, and at a fixed height it opens a valve that admits the air under pressure, and the sewage is thereby rapidly displaced. As the float drops it cuts off the air pressure, by which a further charge of sewage is admitted. This apparatus is serviceable as a means of avoiding deep sewers, and heavy pumping, over

comparatively flat areas, or where the outfall is not at all times free. The rapid action of the Ejector has an advantage in discharging sewage from the low-level sewer to the higher level very quickly, which produces a flushing action.

A recent arrangement for a similar purpose is the sewage lift of Mr. Adams. This apparatus has for its object the raising of sewage from a low level by means of air pressure obtained from a head of sewage at a higher level. This is effected by employing two closed receptacles, called the air and the forcing cylinders respectively, connected by an air pipe. The forcing cylinder receives the sewage at the low level, and the air cylinder receives sewage from an automatic flush tank where it is discharged intermittently at the higher level, displacing the air from the air cylinder, and giving the required head or pressure to the column forcing the low-level sewage to the higher level. The operations of filling and discharging are governed by suitable automatic valves.

Water pressure can be employed to effect the same object—as in Davey's differential hydraulic pumps, which also work automatically. The Hon. R. C. Parsons, C.E., has employed hydraulic power in draining the low-lying districts of Buenos Ayres by automatic pumping at numerous small stations, thereby avoiding deep sewers. There are in all 17 of these stations, and water pressure at 750 lbs.

per inch is supplied from a central station through $8\frac{1}{2}$ miles of mains from 5 inches to 2 inches in diameter.

Electricity, developed at a distant point, can also be utilised to work motors for raising sewage in a similar way, at places where there may be objections, either engineering or sentimental, to the establishment of a steam pumping station.

CHAPTER X.

SEWAGE SLUDGE.

The sludge derived from chemical precipitation processes used to be regarded as a source of wealth, and much attention was bestowed on the subject by those who hoped to obtain the theoretical value of the fertilising ingredients contained in it; but these anticipations have not been realised. The practical conclusion is that sludge has no recognised value to justify its being regarded other than as a product to be got rid of in the simplest and cheapest way. Small quantities can be disposed of by digging it into suitable land, not impervious, but open and porous. An economical plan for dealing with small quantities of sludge is to run it over beds of porous ashes, or ballast from burnt clay, or to mix it with dry road-sweepings. The bulk of the liquid mechanically sinks through such materials, leaving that which can be readily lifted by the spade or fork and carted on to land. At Ealing, Mr. Jones, the engineer to the local board, mixes the sludge with the house refuse, and burns it in a refuse destructor. The sludge at the Barking and Crossness outfalls is conveyed, in its liquid form, in sludge vessels, and is discharged

into the sea. Some experiments were made by Mr. Dibdin, the chemist to the London County Council, as to the composition of this sludge when pressed, and the following are his analyses :—

AVERAGE COMPOSITION OF PRESSED SEWAGE SLUDGE FROM CROSSNESS.

	Per cent.
Moisture	58·06
Organic matter	16·69
Mineral	25·25
	100·00

The organic matter contains—

	Per cent. on Pressed Sludge.	Per cent. Nitrogen.
Saline ammonia	0·035	0·87
Organic nitrogen calculated as ammonia	1·025	

The mineral matter contains—

	Per cent.
Carbonate of lime	7·94
Free lime	2·45
Silica	8·08
Oxide of iron	0·97
Oxide of alumina	3·39
Phosphoric acid (= phosphate of lime 1·44)	0·658
Magnesia	traces

Sludge from any system of sewage disposal consists of about 90 parts of water and 10 parts of solid. As the sludge is dried its weight diminishes in a ratio which it may be useful to define by the following simple rule, which the author gave in his book on Sewage Disposal published some years ago.

Let X = weight of sludge to be ascertained;
S = weight of solids in the sludge (which is constant);
P = percentage of moisture in the sludge.

Then

$$X = \frac{S \times 100}{100 - P}.$$

For instance, to ascertain what weight 25 tons of sludge containing 90 per cent. of moisture would be reduced to when it is dried to 15 per cent. of moisture:

Twenty-five tons of sludge with 90 per cent. of moisture contain 2·5 tons of solids (which is constant); therefore, applying the formula

$$X = \frac{2 \cdot 5 \times 100}{100 - 15} = 2 \cdot 94 \text{ tons.}$$

The following shows the diminishing weights of 100 tons of sludge with proportions of moisture varying from 90 to 15 per cent.:—

		tons.		per cent.
100 tons with 90 per cent. of moisture	.. =	50	with	80
” ”	.. =	33·3	”	70
” ”	.. =	25	”	60
” ”	.. =	20	”	50
” ”	.. =	16·6	”	40
” ”	.. =	14·3	”	30
” ”	.. =	12·5	”	20
” ”	.. =	11·76	”	15

DR. WALLACE'S ANALYSES (

Name of Town.	Aylesbury.	Birmingham.		Bolton.
Process of Precipitation.	A B C.	Lime. 1	2	Lime and Charcoal
Date.	1879.	1879.	1879.	1879.
Water..	12·60	12·70	13·16	14·34
Organic matter, carbon, &c. ..	35·60	19·19	20·04	26·18
Phosphoric acid	2·11	·40	·72	·62
Sulphuric acid	2·70	1·45	·35	·61
Carbonic acid	..	7·62	8·53	8·30
Lime	2·18	11·19	12·74	14·50
Magnesia	·18	·90	1·37	1·06
Oxide of iron	6·20	2·70	3·20	1·98
Alumina	6·75	2·68	2·58	2·97
Sand, &c.	33·50	41·13	37·93	29·50
	101·22	99·96	100·62	100·06
Phosphate of lime	4·61	·87	1·57	1·35
Nitrogen	1·60	·52	·49	·61
Equal to ammonia	1·94	·63	·60	·74
Calculated value per ton	*s.* 33	*s.* *d.* 10 9	*s.* *d.* 11 5	*s.* *d.* 13 4

SEWAGE SLUDGE (AIR-DRIED).

Bradford.		Coventry.		Leeds.		Leicester.	Windsor.
Lime.		Sulphate of Alumina.		Modified. A B C.	Hanson's Process.	Lime.	Hillé's Process.
1876.	1879.	1877.	1879.	1876.	1876.	1879.	1877.
8·90	6·92	14·04	10·04	9·56	16·40	11·93	11·76
33·75	34·53	20·58	23·09	20·82	27·92	22·18	12·06
·80	·73	1·56	2·07	·64	·75	1·21	·87
·64	1·74	1·32	·56	2·15	1·02	·51	·49
10·53	13·77	6·64	5·71	8·42	13·11	15·25	22·71
16·90	20·27	9·16	6·65	9·68	17·51	20·16	31·09
1·66	5·07	·86	·61	5·64	7·67	1·48	1·58
2·11	2·01	4·14	2·66	4·61	2·32	2·66	1·68
3·49	3·89	4·13	5·80	7·04	6·30	1·63	2·31
21·80	10·23	37·83	42·00	31·60	7·36	22·30	14·16
100·58	99·16	100·26	99·19	100·16	100·36	99·31	98·71
1·74	1·59	3·40	4·52	1·39	1·64	2·64	1·90
·62	·66	·92	1·27	·66	·70	1·08	·52
·76	·80	1·11	1·55	·80	·84	1·31	·63
s. d. 15 1	*s. d.* 15 4	*s.* 20	*s. d.* 27 2	*s. d.* 14 2	*s. d.* 17 2	*s. d.* 21 7	*s. d.* 11 5

Chemists base the value of sludge on the proportions of ammonia, phosphate of lime, &c., and it is assumed that these are capable of being assimilated by plants. Mr. Warington, in his valuable researches into the production of nitrates in the soil, found that nitrification, like all other kinds of fermentation, is affected by the presence of antiseptics. This may account for the sludge from chemical-precipitation processes not producing the agricultural results which, theoretically, were anticipated, or to the sludge being applied before it has recovered from this arrested putrefaction.

In 1879 Dr. Wallace made a report to the Corporation of Glasgow, assigning values to air-dried sludge from various precipitation processes, and it contained the table on pages 148, 149.

Dr. Munro has given much consideration to the manurial value of sludge, and a paper read by him before the Chemical Society, contained the table on page 151 as the outcome of a series of experiments that he had made.

Dr. Munro estimated that sludge which had been produced from a lime and sulphate of alumina process was worth 6*s.* 6*d.* a ton, valuing nitrogen at 12*s.* per unit, and precipitated phosphoric acid at 5*s.* 6*d.* per unit. He stated that dried sludge, on an average, contained 2·20 per cent. of phosphoric acid, equivalent to 4·80 per cent. of phosphate of lime, and 1·405 per cent. of nitrogen, equivalent to

COMPOSITION OF SEWAGE SLUDGE. (DR. MUNRO.)

—	Coventry (Dried). (Lime and Sulph. Al.)		Leyton (Dried). (Lime and Sulph. Al.)		West Ham (Dried). (Lime.)		Wimbledon as from Press (Lime Process).[1]
Organic matter	..	26·14	..	26·08	..	40·32	Water .. .. 56·15
Containing nitrogen	1·36	..	1·35	..	1·82	..	*Organic matter 11·36
Ash	..	..	..	..	..	..	Insoluble silicate matters 7·10
Soluble in acetic acid.							
Carbonate of lime	39·07	..	26·36	..	23·72	..	Phosphoric acid P_2O_5 1·96
Ammonia ppt. 1·49 — Phosphoric acid	0·c5	..	0·29	..	0·38	..	Equivalent to tri-basic phosphate of lime, Ca 3 P 2 O 5, 4·28.
Ammonia ppt. 1·49 — Oxide of iron, alumina, and soluble silica ..	1·44	..	7·42	..	1·93	..	
Ammonia ppt. 1·49 — Potash	trace	..	..	..	..	..	
Soluble in hydrochloric acid.							
Ammonia ppt. 9·64 — Phosphoric acid	2·38	..	1·75	..	2·19	..	Carbonate of lime, oxide of iron, alumina, magnesia, sulphuric acid, chloride of sodium, potash, &c. 23·43
Ammonia ppt. 9·64 — Oxide of iron, alumina	7·26	..	7·79	..	8·09	..	
Ammonia ppt. 9·64 — Potash	0·30	..	0·34	..	0·22	..	
Insoluble.							
Sand and silicates	22·84	..	26·21	..	18·30	..	
	73·34	..	70·16	..	54·83	..	
Magnesia, sulphuric acid, sodium, chlorine and loss	0·52	..	3·76	..	4·85	..	
		73·86		73·92		59·68	
		100·00		100·00		100·00	100·00
Total, P_2O_5	2·43	..	2·04	..	2·57	..	
Citrate soluble, P 2·65	1·37	..	1·69	..	1·24	..	
Air-dried as used in expl. plots.							
Water	36·23	..	21·16	..	15 43	..	
Organic and volatile matters ..	16·67 (containing nitrogen)	0·87	20·56 (containing nitrogen)	1·06	34·10 (containing nitrogen)	1·54	
Ash	47·10 (containing P_2O_5)	1·55	58·28 (containing P_2O_5)	1·61	50·47 ,,	2·17	
	100·00		100·00		100·00		

*Containing nitrogen, 0·41, equivalent ammonia = 0·50.[1]

[1] At the time the analysis was made, the sewage was treated with lime only.

1·706 per cent. of ammonia. The manurial value of the constituents of average dried sewage sludge he estimated to be 31*s*. 9*d*. per ton.

The two following experiments of Dr. Munro deserve quoting:—

	lb. tubers.
39 sets of potatoes unmanured produced on an average	64
39 sets of potatoes each manured with 4 oz. dried and ground Coventry sludge, containing 13½ per cent. moisture, 1·06 per cent. nitrogen, and 1·25 per cent. phosphoric acid, produced on an average	76
39 sets with 8 oz. per set of similar sludge, produced	86
39 sets with 1 oz. per set of fish guano, containing 8 per cent. nitrogen and 17 per cent. phosphate of lime, produced	72
39 sets with 2 oz. per set of similar fish guano, produced	102

In a crop of rape the following were the results:

	lbs.
The unmanured plots produced on an average	153
4 cwt. per acre of fish guano produced an increase over this of	121
8 cwt. per acre of ordinary superphosphate gave an increase of	175
1½ ton per acre of dried and ground Leyton sludge (moisture 27 per cent., nitrogen 1·05 per cent., phosphoric acid 1·28 per cent.) gave an increase of	192
10 tons per acre of farmyard manure gave an increase of	296

In 1894 a return was obtained by the Local Government Board, from towns in which sewage precipitation works were in operation, to ascertain if the precipitate was saleable. Two hundred and thirty-four places are given in the return, and at only thirty places was anything obtained for the sludge, the amount varying from 1*s.* to 2*s.* 6*d.* per ton.

Sewage sludge is usually converted into a portable material in filter presses, made by Johnson & Co., Manlove Alliott & Co., and others. The principle of construction consists generally of a series of circular or square iron discs, the faces of which are grooved and recessed, and are covered with a filter cloth. The plates slide on guides, and when they are close together they form a nearly cylindrical mass of discs, with hollow spaces between them into which the wet sludge is forced, generally by compressed air. The fluid passes through the filtering material to the grooved surfaces of the plates, whence it is conveyed by holes at the bottom of the inner part of the plate to the outside of the press. The solids are retained in the space between the discs, from which they are removed by sliding the plates away from each other on the guides by hand. The author some years ago patented a plan for rapidly opening presses of this kind, by connecting the series of discs together with links, and attaching the whole to a crosshead. This was drawn along the guides, either by a knuckle-joint lever

worked by hand, or by a piston rod actuated by compressed air or steam, so that, as the piston rod drew the crosshead forward, it was followed by the whole string of discs.

The sludge before pressing is usually stored in an iron receiver, into which it is drawn from the sludge pit by exhausting the air in the receiver. With some sludges a little lime is added for the purpose of assisting the water to filter through the cloths. The sludge is generally forced from this receiver into the interstices of the discs of the filter presses by compressed air, at from 60 lbs. to 100 lbs. per inch, which being turned into the receiver displaces the sludge. It is sometimes pumped direct from the sludge pits without a receiver. The cost of converting fluid sludge into this pressed cake is from 2*s.* to 2*s.* 6*d.* per ton of cake containing about 50 per cent. of moisture, in which state it represents approximately one-fifth of its original bulk.

CHAPTER XI.

FILTRATION.

The purification of sewage by passing it through land was considered, a few years, ago to be effected by the oxidation of the organic matter in the interstices of the soil. The researches of Mr. Robert Warington, at Rothampstead (following up some experiments published in 1877 by two French chemists, MM. Schlœsing and Muntz), threw an entirely new light on the subject, and the interesting papers by him, which appear in the Journals of the Chemical Society, of the British Association, and of the Society of Arts, gave the results of his investigations, and proved that the changes which take place in the soil are produced by a nitrifying organism. The practical outcome of these researches is of great importance to the engineer in regard to sewage disposal.

The Annual Reports of the State Board of Health of Massachusetts afford a unique example of carefully recorded observations, of great practical value to engineers.

An extended series of experiments on the filtration of sewage and water was carried on at their

station at Lawrence, from the years 1888 to 1893, but reference will only be made to the sewage filtration experiments, although they have a close connection with the others.

The experiments were made with nine circular tanks, about 17 feet in diameter and 6 feet deep, made of cypress, and puddled so as to be watertight. At the bottom of each tank was an underdrain of horse-shoe shape covered by layers of gravel $3\frac{1}{2}$ inches thick, of varying sizes, the bottom layer being 1 inch by 2 inches, and the fine layer at the top being one-eighth of an inch. Above this substratum the tanks were filled with different materials as follows:—

(1) 5 feet of very coarse clean mortar sand;

(2) 5 feet of very fine, nearly white, sand;

(3) 4 feet of peat, with 1 foot of the top layer originally overlying the peat;

(4) 5 feet of river silt, mostly very fine sand;

(5) 5 feet of good brown soil from a garden that had been manured and cultivated;

(6) 3 feet 8 inches of coarse and fine sand and fine gravel;

(7) The same as No. 6, above which were 10 inches of yellow sandy loam and 6 inches of brown soil;

(8) The same as No. 6, above which were 8 inches of yellow sandy loam, and above this were 8 inches of similar sand and gravel to that beneath;

(9) 4 feet 3 inches of very compact sandy hard pan of clay, sand and gravel, covered with 9 inches of brown soil.

In addition to these large filters there were ten galvanised iron tanks under cover (numbered from 11 to 20), having an area of one-hundredth of the large tanks, or one twenty-thousandth of an acre. These were drained with 5 inches of fine and coarse material as in the large filters. No. 11 tank had 3 feet 8 inches of material like No. 6. Nos. 12, 13, 14 and 20 had five feet of coarse sand like No. 1. Nos. 15, 16, 17, 18 had sand and peat.

The sewage that was experimented with was ordinary city sewage, derived from the stores and dwellings of about 10,000 people, and the object that was aimed at was to learn how to purify it. The sewage from American cities is much more dilute than from European cities. In the former a sewage stronger than usual would contain 998 parts of pure water, 1 part of mineral matter, and 1 part of animal and vegetable matter (see page 9).

The experiments were commenced in view of what had been proved as to nitrification taking the leading part in the purification of sewage, and that it was essential to produce the conditions most favourable to develope nitrifying organisms. An elaborate series of observations were recorded to determine the purifying capacity of the several filters, as evidenced by a comparison between the organic

matter in the sewage, and the quantity of ammonia and nitrates in the effluents. The nearer the nitrogen of the nitrates in the effluent approach the whole amount of nitrogen in the sewage, the more completely has the desired change been effected. The experience of the winter of 1887–1888 showed that nitrification did not begin until the effluent from a tank reached a temperature as high as 39° F. It may be noted that Mr. Warington pointed out that the oxidising power of the soil was greater in the summer than in winter. Also that the analyses of sewage effluents from land filtration would vary, owing to the nitrates produced in summer being assimilated by the growing crops, whereas in winter-time they would pass off with the subsoil water.

The experiments on filter No 1 commenced in January 1888, by passing river water through it for a month at the rate of 1000 gallons a day, at a temperature of 45° F. Sewage was then first applied in small quantities, with interruptions due to obstructions to the filter from the formation of ice, the temperature for some weeks being 5° below zero on an average, and holes had to be cut into the filter to keep it open. For part of March and to the end of April 150 gallons a day were applied, the temperature of the effluent being uniformly 36°. The nitrates of the sewage were very constantly 0·01 part in 100,000 parts. The nitrates of the

effluent varied, rising during April to 1·00 part per 100,000, the temperature of the effluent being 39°, and still further rising to 3·00 in May, with a temperature of 50°, and averaging for that month 1·97 parts per 100,000. The quantity of sewage passed through the filter in the earlier four months of 1888 was at the rate of 30,000 gallons per acre per day, and double that in the later months. This larger quantity was applied for a year, none being applied on Sundays, a double dose being applied on the Saturday.

The experience of the first winter showed that nitrification did not begin till the temperature of the effluent was 39°. The following winter was less severe, and the sewage was applied to the filters at a temperature of 45°, that of the effluent being about 40°. During the four cold months of 1888–89 53 per cent. of all the nitrogen in the sewage was found in the effluent, whilst in the four previous months, August to November, only 33 per cent. was found, showing that when nitrification had been once established it continued, even when the temperature of the sewage was as low as 35° and that of the effluent 33°. On the advent of spring, nitrification became more complete, averaging in April 81 per cent., in May 90 per cent., of the total nitrogen in the sewage, and varying during the other months from 79 to 45 per cent. The six months (May to October) of the second year gave an average of 63 per cent.

compared to 41 per cent. in the corresponding period of the previous year, the filter having been continuously at work for two years without any renewal of material, or removal of sediment.

In all the filters the same conditions obtained in regard to bacteria. As soon as the filter got into full operation, and nitrification was established, it was found that, over a period of a year and a half, the bacteria in the effluent were generally a very small fraction of 1 per cent. of the number in the sewage. In regard to the distribution of the bacteria in the filter, it was found that the numbers decreased rapidly from the top downwards, only about 3 per cent. being in the bottom inch of the number in the top inch. Through the 5 feet of coarse sand in filter No. 1 (0·06 of an inch in diameter), from 26 to 40 per cent. of bacteria passed. Through sand a tenth finer, in filter No. 2, 14 per cent. passed. Through river silt, in filter No. 4, 5 per cent. passed. Filter No. 6, with 3 feet 8 inches of coarse and fine sand and fine gravel, 5 per cent. passed through. Filter No. 5, with 5 feet of good brown garden soil, as well as peat, practically none passed through.

In this connection it may be mentioned that Miquel states, in the 'Manuel pratique d'Analyse bactériologique des Eaux,' that the sewage of Paris, containing about 13,800,000 bacteria per c.c., is deprived of all but between 7000 and 8000 after

passing through the sandy soil of the sewage farm at Gennevilliers.

During 1890, sewage was filtered through a bed of washed gravel stones five feet deep. For nine months sewage was applied nine times a day for six days in the week, in quantity equivalent to 81,400 gallons per acre per day (or 70,000 gallons per acre per day all the year), with the result that 98·6 per cent. of the organic matter in the sewage was converted into nitrates, and more than 99 per cent. of the bacteria were destroyed. The quantity was then increased by applying the same amount hourly for fourteen, instead of nine, hours. This was equivalent to 126,000 gallons per acre per day for six days in the week for three months, ending October 24, when 98·5 per cent. of the organic matter was found to have been converted into nitrates, and more than 99·6 per cent. of the bacteria were destroyed. In November the quantity was again increased.

The results of the experiments may be summarised in a general way as follows.

Gravels and sands, from the coarsest to the finest, enable purification by nitrification to take place when the quantity of sewage is adapted to their capability, and when the surface is not allowed to become clogged by organic matter, to the exclusion of air. With fine soils resting on fine sandy material, excellent results can be obtained, but at a very slow rate

of purification, due to the time occupied in getting the sewage through the filter, and in resting it for the air to enter and effect nitrification. Filters with a greater depth of such fine material are useless, as they became practically always saturated, and as inoperative as if the sewage was being passed continuously. With peat upon the surface of a filtration area, even to a depth of only one foot, its imperviousness to liquid, and the quantity that it will retain, render intermittent filtration impracticable under those conditions.

The experiments with gravel stones afforded the best illustration of what takes place in the purification of sewage. The slow movement of the liquid (even with the coarser suspended matters contained in the sewage) in thin films over the surface of the stones, in contact with air, caused 97 per cent. of the organic nitrogenous matter—a large part of which was in solution—as well as 99 per cent. of the bacteria, to be removed during a period of some months. There remained in the effluent only three per cent. of the decomposable organic matter of the sewage. The presence of bacteria was essential to produce this nitrification, which was found to be highest in all the filters from the end of April through May and June.

The table on page 163 summarises part of the work done at the Lawrence Station in 1893.

RESULTS OF SEWAGE FILTRATION AT LAWRENCE IN 1893.

Number of Filter.	Dimensions of Filters. Depth of Sand. Inches.	Dimensions of Filters. Area in Fractions of an acre.	Size of Sand. Effective Size in Millimetres 10 per cent. Finer than	In Operation since	Average Rate of Filtration. Gallons per acre daily for six days in a week.	Per cent. of Albuminoid Ammonia removed.	Per cent. of Bacteria removed.
1	63	$\frac{1}{200}$	·48	Jan. 10, 1888	106,000	86	89
2	60	$\frac{1}{200}$	·08	Dec. 19, 1887	40,500	97	99·8
3A	60	$\frac{1}{200}$	{·48 ·08}	Jan. 6, 1890	56,300	91	99·9
4	60	$\frac{1}{200}$	·04	Dec. 19, 1887	32,300	96	99·9
5A	63	$\frac{1}{200}$	1·40	Sept. 14, 1891	119,000	82	77
6	44	$\frac{1}{200}$	·35	Jan. 12, 1888	73,300	91	99
7	44	$\frac{1}{200}$	·35	Jan. 14, 1888	32,000	92	99·8
9A	60	$\frac{1}{200}$	·17	Nov. 18, 1890	111,700	92	99
11A	60	$\frac{1}{20000}$	·35	Mar. 30, 1892	58,900	89	95
13	63	$\frac{1}{20000}$	·48	Feb. 16, 1888	154,100	91	95
14*	63	$\frac{1}{20000}$	·48	Feb. 16, 1888	174,000	95	96
15B	65	$\frac{1}{20000}$	5·10	July 25, 1892	404,700	77	77
16B	65	$\frac{1}{20000}$	5·10	July 25, 1892	415,200	75	81
17A	60	$\frac{1}{20000}$	·17	Jan. 28, 1890	58,500	95	99·9
30	30	$\frac{1}{27900}$	·48	May 31, 1890	55,100	90	97
31	30	$\frac{1}{27900}$	·17	May 31, 1890	55,100	96	99·9

* Contains layer of polarite.

The Lawrence experiments showed that, while some of the large outdoor filters were doing good work, after four years of continuous use, some had stored so much organic matter as to seriously cripple them, and this was always where the materials were fine sand, sometimes with coarser sand. The practical remedy is either to give the filter rest, so that it may regain its purifying action, or to remove the clogged part until it has purified itself. The storing of such material is not productive of a nuisance, as it contains the most stable portions of the sewage, which, having resisted strong oxidising action, are incapable of rapid, or objectionable, decomposition. Filter No. 6, after being at work for four years, had filtered sewage equivalent to 15,000,000 gallons per acre per annum. To restore this filter would only involve the removal of the upper 2½ inches. On a large scale, what would have to be done would be to rake, spade, or plough the surface to a greater or less extent, and let it rest. As the clogging is mainly due to the sewage not having time to get purified, intermittency of application is essential, and frequent small doses are better than large ones. Stored organic matter will disappear with rest, and may be regarded as amenable to good management.

The average results from all the Lawrence sewage filters, some of which have been at work for six years, indicate that they may continue to purify

sewage for an indefinite time, provided they receive proper treatment to ensure nitrification.

As the filtration of sewage requires to be dealt with from considerations that apply also to the filtration of impure water, some reference may be made to the investigations of Dr. Percy Frankland in regard to the bacteriological examination of waters. In a paper read at the Parkes Museum this year he gave some very interesting conclusions as the outcome of a long series of observations on the filtration of water. With respect to sand filtration, it was pointed out that chemists had not regarded it with much favour, but he found that although sand filters were comparatively inert from a chemical point of view, they are superior to almost any other filters hitherto devised in their extraordinary power of removing bacteria, principally owing to the production of a layer of slimy silt on the surface of the sand. This layer takes some time to form, and its removal impairs the efficiency of the filter until it has reformed. Recent investigations have shown that even after passing through this layer of surface slime, very considerable numbers of bacteria still remain in the filtrate, and that to obtain a satisfactory filtrate it is essential that the water should pass through a layer of sand not less than 15 to 24 inches in depth. It is, moreover, of importance to hasten the formation of surface slime, and to this end the water should be run on to the

filters, and left there undisturbed for twelve hours before filtration is actually commenced.

Mr. W. J. Dibdin has carried out a series of experiments, at the London County Council outfall works at Barking, with a view to determining the best methods of filtering the effluent from the precipitation tanks. Two series of experiments were made: the first with four small filters each $\frac{1}{200}$ of an acre, and with various filtering materials; the second on a filter one acre in area, and using only coke breeze.

The four small filters were all worked at the same rate, and during the same hours, and the following description of the results is obtained from a report of Mr. Dibdin's to the London County Council, of September 1895.

Filter No. 1 consisted of burnt clay ballast 4 feet thick. Effluent sewage was passed through it at an average rate, inclusive of rest periods, of 411,000 gallons per acre per 24 hours. The average purification effected was 43·1 per cent.

Filter No. 2 consisted of 4 feet of Lowestoft shingle of pea size. The purification effected was 52·3 per cent.

Filter No. 3 consisted of coke breeze to a depth of 4 feet, with 3 inches of gravel on the top to prevent the coke from floating. The average purification effected was 62·2 per cent.

Filter No. 4 had an area of $\frac{1}{300}$ of an acre,

and was made up as follows, from below upwards: 5 inches of walnut-size gravel, $2\frac{1}{2}$ inches of bean-size gravel, $1\frac{1}{2}$ inches of pea-size gravel, and 10 inches of sand. It formed part of the filter, hereafter referred to, in which a layer of polarite was added. The effluent was passed through at the rate of one-half more per square yard than in the case of the other filters. The sand filtration was stated to be preliminary to the treatment with polarite, the areas of the two portions being equal to one of the filters already described. The average purification was 46·6 per cent.

Filter No. 5 contained an area of eight square yards, and consisted of the following, in order from below upwards: 3 inches of walnut-size gravel, 2 inches of bean-size gravel, $1\frac{1}{2}$ inches of pea-size gravel, 1 inch of sand, and 12 inches of polarite. The effluent which it received had already passed through filter No. 4. The rate of filtration was three times that of the others, so as to bring up the rate of the combined filter to an equality with the rest. The average purification effected was 61·6 per cent.

The average rate of working, including periods of rest, was 411,000 gallons per acre in 24 hours.

The report states that burnt ballast or gravel may be made much more efficient by using a greater depth of more finely granulated material, with a slower rate of filtration; and it was considered that

the polarite filter "excelled the coke breeze only in appearance, the actual purification not being quite so much, while the cost is prohibitory."

Observations were made as to the number of micro-organisms that were present in the effluents before filtration and in the filtrates, and they varied largely, more being generally found in the filtrates. This was not regarded as any indication of the degree of purification effected, the presence of a large number of organisms being evidence of the activity of the process going on of splitting up the organic compound passing through the filters.

In the second series of experiments a filter was constructed covering exactly one acre of land, and this was underdrained. It was converted into a filter, consisting of 3 feet of coke breeze covered with 3 inches of gravel.

The filter was worked at first to see what volume could be passed without reference to results. It, however, soon became clogged with sludge, and after the sixth week all the filtrates were putrid.

The first series of biological experiments was conducted with the preceding filter. The surface was raked, and the bed was allowed to rest during three and a half months. For fully three months of that time a putrid odour was observable when the filter was disturbed, but this gradually disappeared, and, during the last fortnight, the coke breeze was perfectly sweet. From that time the filter was kept

practically at work for nearly a year, the only rest of any length being from the 17th of November, 1894, to the 2nd of January, 1895, when alterations in the arrangements were made to admit of more rapid emptying.

The process adopted was to begin with small quantities, the filter being merely filled and emptied twice daily, with a view to getting it into the necessary biological condition. This was commenced on 2nd April, 1894, and continued for a few weeks, the purification effected gradually rising. The quantity of effluent passed was about 500,000 gallons per diem, and the purification effected was from 70 to 80 per cent. The highest state of efficiency was reached on the 3rd of May, or after a full month's working, when the purification reached 83 per cent., and fish placed in the filtrate were kept alive for many weeks. In fact, fish (minnows and sticklebacks) came up the ditch, by which the filter was emptied, to the very mouth of the outlet.

Alterations were then made, and the daily quantity was increased to 600,000 gallons a day, with continued highly satisfactory results.

Towards the end of 1894 the emptying arrangements were supplemented by a pump, and, later, the resting time was shortened, until finally the filter passed $1\frac{1}{6}$ million gallons daily for six days, resting empty from 10 P.M. on Saturdays until 6 A.M. on Mondays. The method adopted was to fill the

filter level with the surface as quickly as possible; allow it to remain standing full for one hour, and then draw off with the least possible delay. Working in this way the filter passed an average of one million gallons a day, including all times of rest, during a period of eight weeks, the filtrates being clean and sweet, and the purification effected being 78 per cent. Nitrification proceeded satisfactorily, and the filter was apparently capable of continuing operative for an indefinite time.

The filter was able to do its work satisfactorily during the exceptionally severe weather in January and February 1895. A thin coat of ice was formed on the surface, but the filtration proceeded without intermission, the only noticeable change being the decreased production of nitric acid.

From May until the end of September 1895, the filter was kept continuously at work (except during one week in August), alternately filling, resting full, and emptying, with 24 hours' entire rest each week. The table on page 171 shows the results, the figures given being weekly averages of daily analyses, the samples on which the latter were made being themselves averages of quarter-hour samples from each filling and emptying.

Mr. Dibdin concludes by saying that "the experiments, taken as a whole, show that sewage, especially if previously clarified by precipitation, may be purified to any desired degree, the actual amount of

TABLE SHOWING RESULTS OF EXPERIMENTS BY MR. DIBDIN.

Date. 1895. Week ending—	Quantity of effluent passed daily per acre. Average of 7 days.	Oxygen absorbed in 4 hours. Average of 7 days. Effluent.	Oxygen absorbed in 4 hours. Average of 7 days. Filtrate.	Purification, per cent.
May 4	1,049,776	3·592	·753	79·0
„ 11	1,050,878	3·576	·861	75·9
„ 18	1,128,138	3·867	·865	77·6
„ 25	1,076,939	3·657	·862	76·4
June 1	932,171	4·009	1·013	74·7
„ 8	725,718	3·399	·841	75·3
„ 15	980,408	3·247	·872	73·1
„ 22	925,621	3·496	·698	80·0
„ 29	779,282	3·441	·566	83·6
July 6	959,512	3·576	·614	82·8
„ 13	1,049,042	3·282	·572	82·6
„ 20	956,825	3·219	·531	83·5
„ 27	964,416	2·852	·490	82·8
Aug. 3	839,472	3·359	·538	83·8
„ 17	966,881	2·810	·450	87·6
„ 24	959,341	2·928	·485	83·5
„ 31	966,042	2·670	·467	82·5
Sept. 7	971,502	2·683	·503	81·3
„ 14	1,013,071	2·573	·470	81·8
„ 21	1,014,667	2·746	·461	83·2
„ 28	1,013,071	2·889	·491	83·0

purification depending upon (1) the length of time during which the effluent is allowed to remain in contact with the filter, and (2) the length of time allowed for aeration. If a reduction of 75 per cent. in the oxidisable organic matters in solution be considered as sufficient, the quantity that can be treated per diem on an acre of coke breeze is one million gallons, which gives a required area for the treatment of the whole of the metropolitan sewage—taken at 180 million gallons—of 180 acres only. This rate is probably the highest that can be worked under all conditions of seasons.

"If, however, only the effluents from the strong day sewage were submitted to filtration, as those from the weak night sewage obtained by precipitation after chemical treatment are sufficiently satisfactory, the area required would be proportionately reduced, viz. to about 120 acres."

Lowcock's Filters.

Mr. Sidney Lowcock has experimented with crude sewage, and effluents from chemical precipitation, in specially aerated filters, with a view to effect the nitrification of organic matter continuously by micro-organisms. He constructed a tank 7 feet 6 inches square and 4 feet deep, at the bottom of which he laid 3-inch open-jointed agricultural

drains along the middle, covered with a 6-inch layer of $\frac{5}{8}$-inch broken stone. On this was 15 inches of a fairly stiff clay, mixed with fine engine ashes and building sand in the proportion of two parts soil to one part of each of the others. He introduced into the rough stone a 3-inch perforated pipe, and forced air from a compressor into it. Crude sewage, after being roughly screened, was applied continuously to the filter, into which air was also forced continuously. The sewage was applied at the rate of 263,780 gallons per acre for 24 hours during 19 days, the effluent being clear and colourless, and (after a few days) odourless. A deposit 5 inches deep then covered the filter, which was raked over, and again started with the same dose of sewage. After another fortnight's run analyses were taken, and showed a reduction of 99·1 per cent. in the free ammonia, and 98·5 per cent. in the albumenoid ammonia. In another fortnight the surface had become choked, and the dose was reduced to 66,900 gallons per acre per day, the effluent remaining excellent. After a day's further working the filter was stopped, and 2 inches of the top surface were removed and replaced with fresh clay and sand, after which the experiment was continued with sewage at the higher rate of supply. After a week (the filter having been at work 54 days) the effluent was analysed and contained 0·013 parts free ammonia, and 0·024 parts albumenoid ammonia per

100,000. The material in the tank was found to be quite clean.

The tank was then supplied with effluent, from precipitation tanks in which sewage had been treated with 6 grains of lime and 12 grains of Spence's alum per gallon. Effluent at the rate of 263,780 gallons per acre per day was then applied, the air pressure being continued. At the end of 10 days' continuously working the filter effluent was found to have improved the tank effluent by reducing the free ammonia from 4·530 to 0·0112, and the albumenoid ammonia from 0·052 to 0·0325. The effluent from the filter was clear, bright and odourless. The filtering material had then been in use eighty-eight days

Another experiment was made with the tank filled up with 6 inches of rough stone broken to pass through a sieve with 1-inch mesh, laid over the drain pipes, then a 3-inch layer of finer stone broken to pass through a $\frac{5}{8}$-inch mesh, then $10\frac{1}{2}$ inches of stone that passed through a sieve having 70 meshes to the square inch. A top layer of 3 inches of building sand was added. The air pipe was placed as before. The effluent from the tanks, before being passed to the filter, had the larger particles removed by passing it through another filter, after which it was applied at the rate of 484,000 gallons per acre per day. In four days the liquid disappeared, then it formed a film, and the quantity was reduced to 373,800 gallons per acre per day, and after another

day to 178,000 gallons, when the surface cleared itself, and the flow was increased to 263,780 gallons for four days, when the surface was raked over and the flow increased. After the filter had been at work 41 days the surface became so dirty that the experiment was stopped, and an examination of the material in the filter showed that with the exception of the actual surface there was no change whatever. It was perfectly clean, and had an earthy smell. The result of these experiments led Mr. Lowcock to adopt a filter made up of a bottom layer of 12 inches of pebbles (surrounding underdrains), over which were 6 inches of bean gravel, 2 feet 6 inches of pea gravel, 12 inches of pebbles (with air pipes for air to be forced in by blowers), 4½ inches of bean gravel, 4½ inches of pea gravel, and a top layer of 9 inches of sand. The surface of the filter is divided up into small areas, by divisions extending a short distance below the top layer of sand, so that the sewage can be diverted from any section for clearing the surface.

Scott Moncrieff's Cultivation Filters.

Mr. Scott Moncrieff claims to have discovered a new departure in regard to utilising the microbe for sewage purification, and has experimented on a practical scale. He considers that the conditions

leading to the nitrification of organic matter when it is passed through land, may be regarded as a dry, or at most a moist process, as compared to the conditions which obtain when the organic matter is undergoing changes in large volumes of water. The biological relations in these two circumstances should be considered, as even if the organisms which produce the changes were the same, the limitations under which they would have to survive and work, when changed from one condition to the other, would be altered.

What takes place in nature, and in the laboratory, when micro-organisms are at work, in producing the changes from the organic to the inorganic state, is liquefaction, or the conversion of the organic substance into a liquid equivalent, and to fulfil these conditions no deposition of the sludge precedent to the sewage being dealt with on this hypothesis is necessary. If this liquefaction is accomplished, Mr. Scott Moncrieff contends that it is the first step in a natural process, which is likely to be more favourable to a second, than any method outside the sphere of biological processes altogether; and he considers that the deposition, or chemical precipitation, of the organic matter in tanks practically removes the organic matter from the conditions favourable to its liquefaction. As the organisms that produce liquefaction in the laboratory work upon the surfaces of the culture plates and tubes,

so will the organisms of liquefaction in sewage work upon the surfaces of stones. All that is required is (1) that no extensive fermentative changes should have previously occurred; (2) that the products of liquefaction should be constantly removed. He contends that by conveying fresh sewage into a restricting chamber covered with a grating, and allowing it to flow upward through flints, the organic matter is brought completely into solution. No suspended matter remains, and the effluent contains the original organic matter in the sewage, in a condition highly susceptible to further disruptive changes, as it is in process of change from the organic to the inorganic state.

The first step in the conversion being liquefaction, every effort should be made to effect it by providing means to secure the most rapid and complete liquefaction without nuisance, and the production of an effluent from the liquefying process which shall be as susceptible as possible to further changes, culminating in the complete resolution of the organic constituents of the sewage.

The apparatus to effect this should possess a large amount of surface with which the organically contaminated liquid is always coming in contact. The liquefaction which occurs in drains and sewers is dependent upon their internal surfaces, which provide a breeding and feeding ground for the liquefying organisms. In contrast to this, a cesspit

has not sufficient surfaces, and is analogous to the nutrient contents of a glass tube in the laboratory, where a rapid growth of organisms, accompanied by liquefaction of the gelatin, takes place, but in which the development of the organisms, and their action upon the organic contents, is suddenly arrested, after the second or third day, by the evolution of products that are fatal to the continuation of the process. From this it appears that something more than mere surface is required, and that the two main factors necessary are not only providing sufficient surface, but also some means for the continual passing away, from that part of the apparatus where the active process of liquefaction is carried on, of the products of the organisms which are destructive of their operations.

In any apparatus that is to provide both of these necessary conditions simultaneously, the supply of fresh nutrient material must be continuous, and there must be no residual spaces where the deleterious products can accumulate. It is also necessary that the organisms of liquefaction must be free to move away from the relatively poisonous contents of the apparatus, towards the supply of nourishment which is for the time being free from these hurtful products. Mr. Scott Moncrieff contends that a downward movement of sewage through a filter does not supply these required conditions, however it may be arranged, or whatever may be the materials composing it. If

the effluent be drawn from the bottom of a downward filter, then the more solid organic matter must be left on the top, and, gravity acting in the same direction as the flow, the interstices of the apparatus will become filled with unliquefied material. If, on the other hand, upward filtration is employed, gravity acts in a contrary direction to the direction of choking, and in this way the organic matter, having a tendency to remain behind, has time for complete liquefaction. The apparatus should be so constructed that no spaces should remain unchanged by the movement of the fluid, and this object is attained by restricting the area of the incoming channel at the bottom of the apparatus, so that the sewage is always free to move through it, and upwards, either vertically or diagonally upon sloping sides, leaving no space unaffected by the general movement, and bringing all the contents in contact with the available surfaces.

To what extent the presence of oxygen is necessary to attain these objects Mr. Scott Moncrieff is not prepared to say. He considers that if the free oxygen contained in the contaminated liquid has previously been used up by fermentative or putrefactive changes, precedent to its treatment in the controlled area, then the liquefaction will take place so slowly that the apparatus may soon be choked. His experiments show that a small supply of oxygen is sufficient, and that fresh sewage contains all that

is required to admit of the apparatus working continuously without cleansing. The functions of the anaërobic and of the aërobic microbes are both in operation, but to what extent requires further elucidation on the part of bacteriologists.

Mr. T. Leone, in a communication to the Chemical Society, pointed out that organic matter was disintegrated by bacteria in the absence of air, by what he termed denitrification. The practical effect of these cultivation filters is, that the solids in sewage are liquefied by the action of certain organisms, which appear in the effluent with nitrates and nitrites, the harmless products of sewage disintegration. Cultivation filters, as Mr. Scott Moncrieff calls them, have been constructed in various places, and the following is a description of one, which was in operation over a period of several months.

The filter bed was about 3 feet deep, 2½ feet wide, and 10 feet in length. The entire sewage discharge and waste waters from a household of from 10 to 12 persons, with the exception of the grease, which was held back as far as possible by a grease-trap, passed into one end of this filter bed. The liquid portion rose through a false bottom, and then through successive layers of flint, coke and gravel, till it reached the level of the outflow pipe, about 2 inches below the level of the invert of the drain. The depth of the filtering medium was only about 14 inches. The cubic capacity of the filter bed was

thus so small that the natural expectation would be that in a few days the filtering medium would become choked, and a nuisance result. As a matter of fact, however, the reverse of this happened, the effluent, up to a certain point, actually improving in quality, and the whole process worked satisfactorily and uninterruptedly for months together without constituting a nuisance.

After the filter had been in use for over two months, the contents below the grating level were cleared out, and the only solid matter found was the last few days' sewage. The whole of the previous solid matter had been converted into a dark coloured and offensive liquid, which was carried into a small trench dug in the ground. The effluent that had resulted from the working of the filter was dealt with by oxidising it in longitudinal nitrifying channels, consisting of half channel pipes filled with coke, with a view to convert the inorganic nitrogen in the effluent into nitrates and nitrites.

The effluent (which had an unpleasant smell) as it passed direct from the filter bed had an alkaline reaction of a grey colour, with a small amount of brown coloured flocculent matter in suspension. The filter bed itself gave off no offensive gases, although it had remained unaërated the whole time. The average of several analyses of the effluent from the filter itself gave 11·6 parts of chlorine, 91 total solids, 5·7 parts of free ammonia, and 0·84

parts of albumenoid ammonia, per 100,000. One cubic centimetre contained 793,750 micro-organisms. Analyses of effluent from two similar filter beds gave better results, the chlorine being 5·4 and 5·7, total solids 54 and 55, free ammonia 2·5 and 1·0, per 100,000 parts, in the two filters respectively.

In working the Scott Moncrieff cultivation filters, what has been observed in all other filters occurred, namely, the necessity for establishing the nitrifying action in the filter. After one of these filters had been in use some months it was cleared out, and new filtering material was put in, when the quality of the effluent at once fell off, but on replacing the old material, in which nitrification had been established, an improvement of the effluent at once occurred.

The effluent resulting from the filter beds being highly charged with nitrifying organisms and nitrates in a harmless form, would be valuable for application to land, or it could continue and complete its nitrification by a subsidiary process. The operations of the filter beds are rapid and continuous, requiring therefore no large tank storage.

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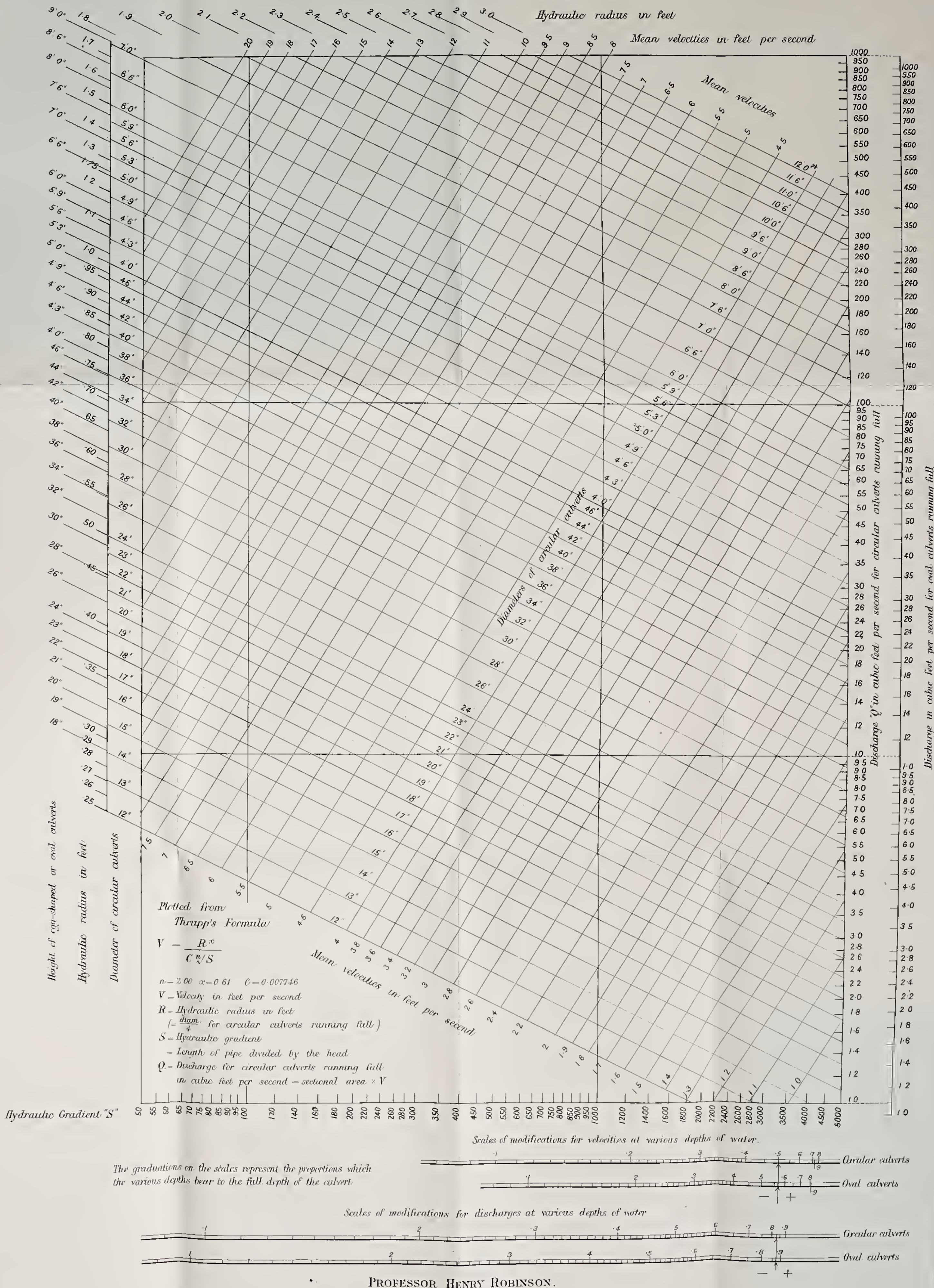

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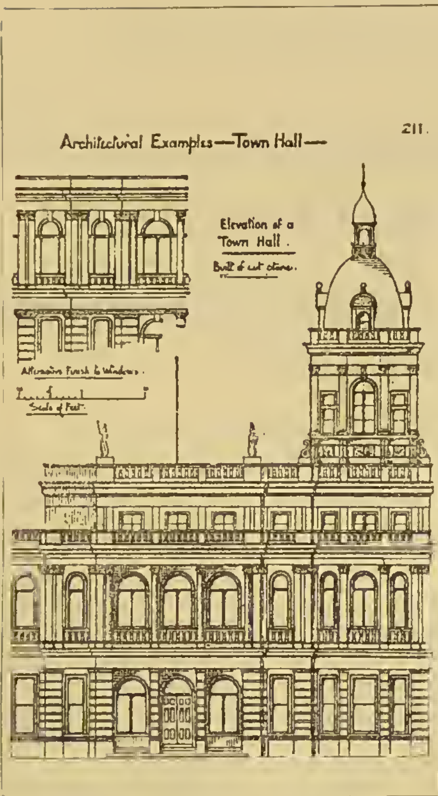

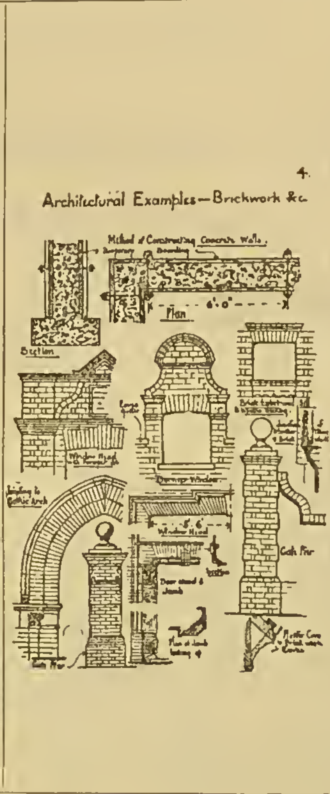

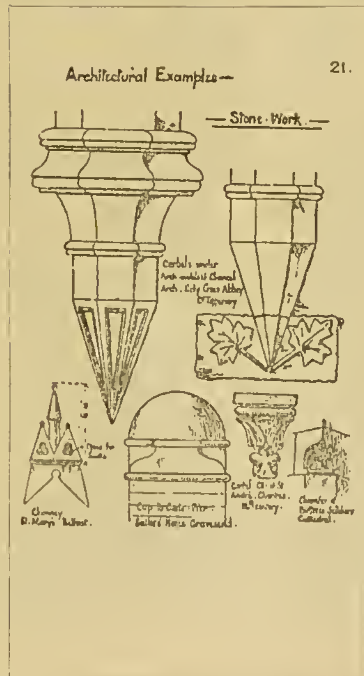

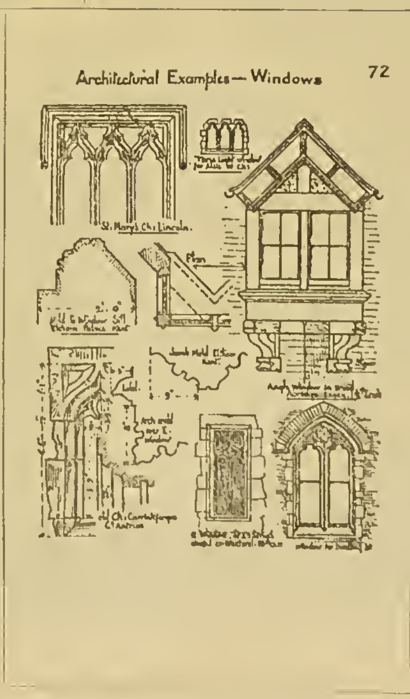

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